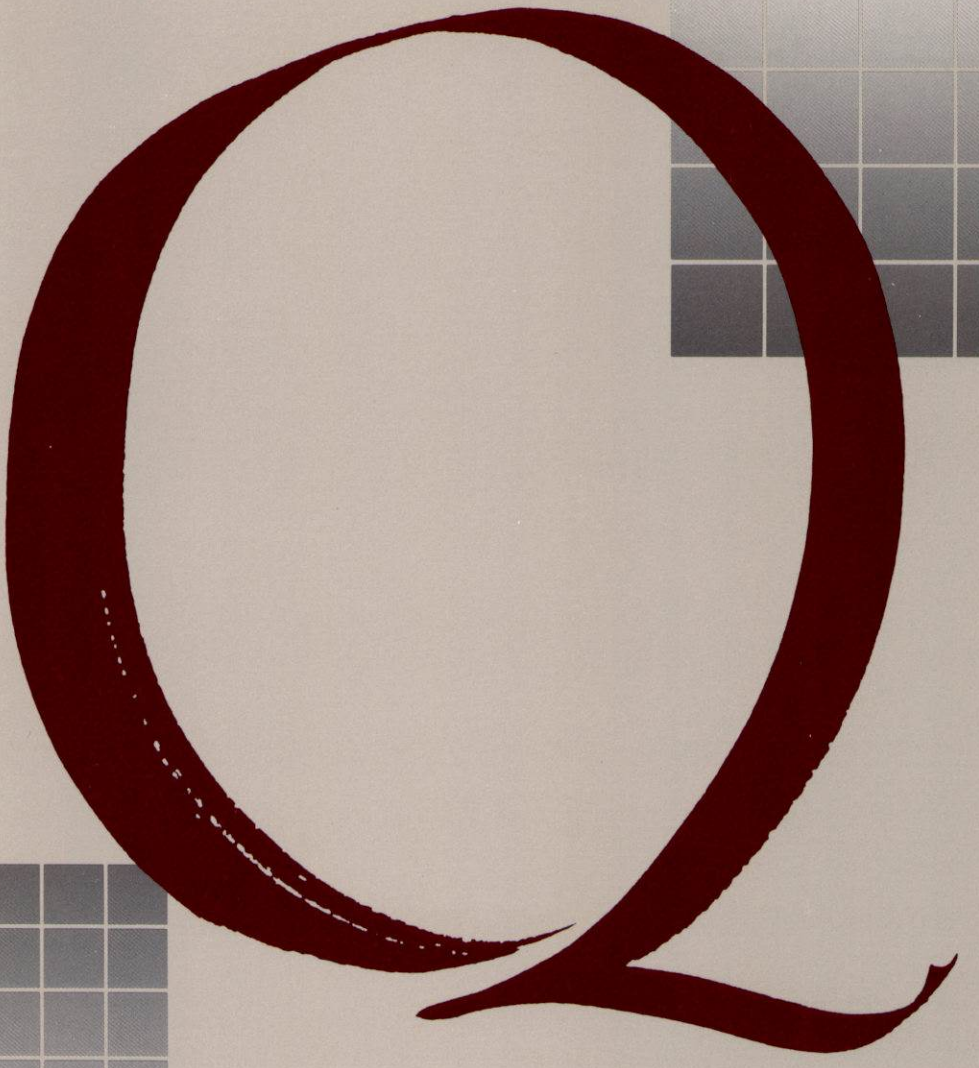
digital

Design for Reliability



Engineering Quality Technology

RELIABILITY/AVAILABILITY PROGRAM

DESIGN FOR SYSTEM RELIABILITY

An Integral Part of the
Engineering Quality Technology Education Program

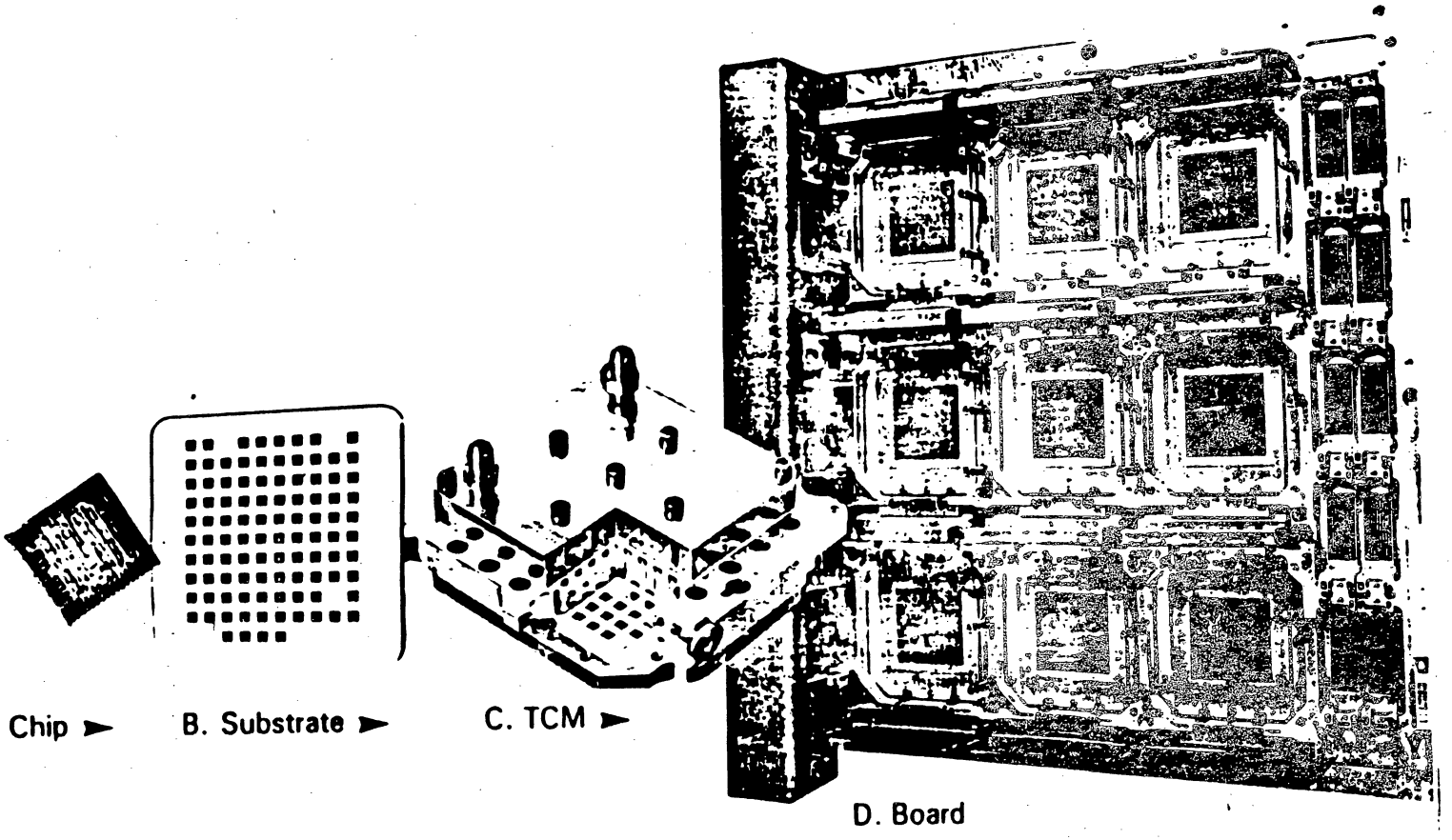
Engineering Quality Technology Group
ZKO2-1/N71
381-1822

Hardware - flows through all five stages

Software - first two stages

Problem - the first two stages are done once per product.

Less data available than the last three stages which are done thousands of times per product.


A. Chip
B. Substrate
C. TCM
D. Board

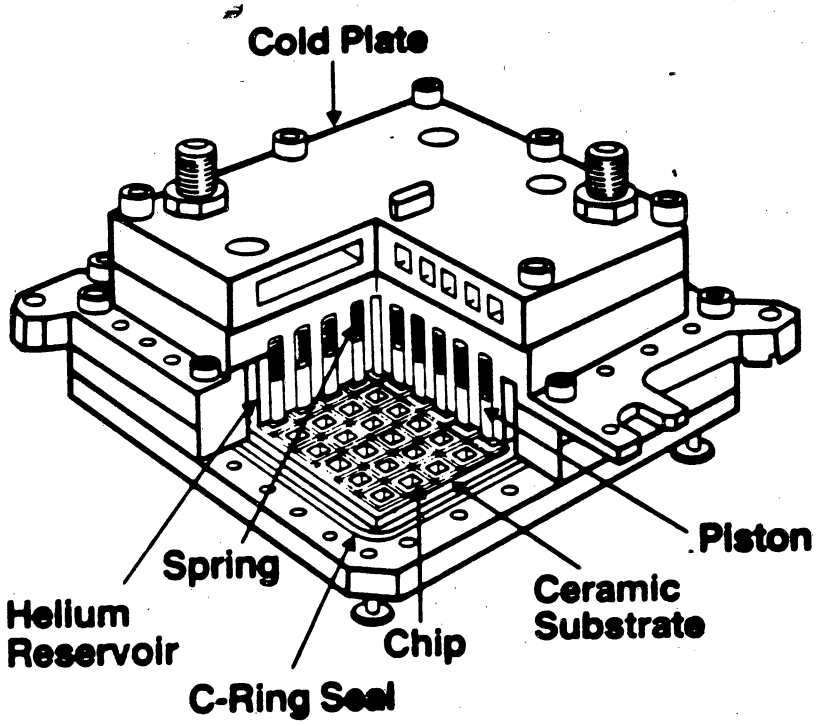


Fig. 1 Thermal Conduction Module (TCM) with water-cooled cold plate

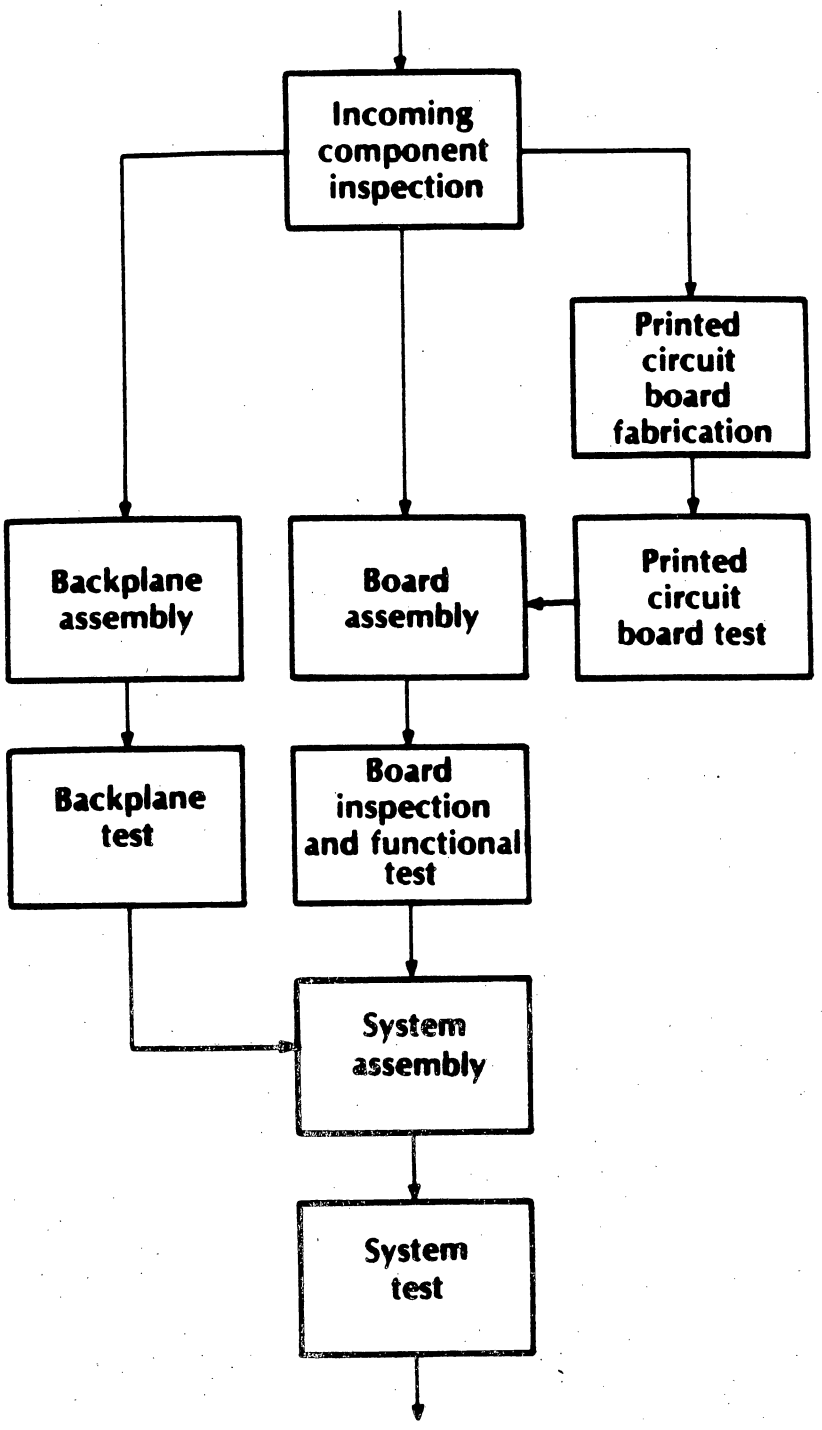


Figure 1–3. Typical steps in the manufacture of a digital system. (© 1979 IEEE.)

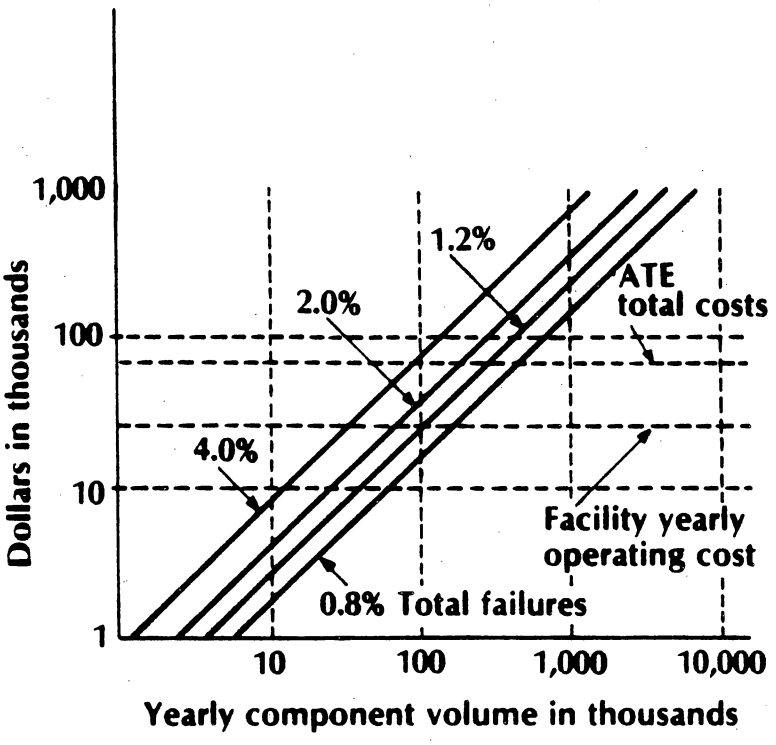


Figure 1-6. Savings from screening and testing as a function of defective component rate and annual device volume.

Hardware Error Tolerance

Advantages

- simplifies recovery for SW end user applications
- saves time
- provides transparency to the user
- decreases MTTR
- increases MTTF, MTTE, MTTC
- error detection logic can help isolate design errors so that future implementations are even more reliable.

Why Design for Reliability

Faults and Their Manifestations

CAUSE-EFFECT SEQUENCE

FAILURE - Physical change in hardware

FAULT - Deviation of logic function from design value

Hard, Transient

ERROR - Manifestation of a fault by incorrect value

FAULT CLASSIFICATION

DURATION - Transient - design errors, environment

- Intermittent) Repair by replacement
- Permanent)

EXTENT - Local (independent)
Distributed (related)

VALUE - Determinate (Stuck at X)
Indeterminate (variable)

WHY DO COMPUTERS STOP?

Jim Gray

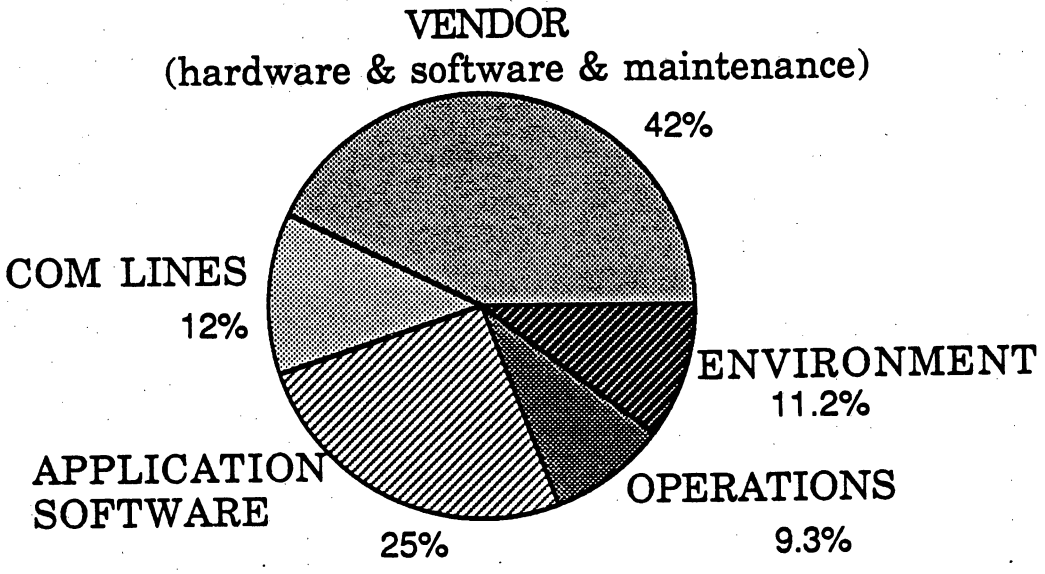
Tandem

Sept 1987

ANOTHER CASE STUDY

JAPANESE COMPUTER USERS

"Survey on Computer Security", Japan Info Dev Corp, March 1986. (trans: Eiichi Watanabe).



VENDOR (HARDWARE & SOFTWARE)	5 Months
APPLICATION SOFTWARE	9 Months
COMM LINES	1.5 Years
OPERATIONS	2 Years
ENVIRONMENT	2 Years
	10 Weeks

1,383 INSTITUTIONS REPORTED (6/84 - 7/85)

7,517 OUTAGES

MTBF ~ 10 WEEKS

AVG DURATION ~ 90 MINUTES

DOES DISC DUPLEXING WORK?

1987 Numbers: 50,000hr MTBF (6 years)
5hr MTTR

=> ~ 65,000 year MTBF

OBSERVED IN LAST 24 MONTHS:
35 double fails on ~46,400 pair/years
~ 1300 years

CONCLUSION:

IT WORKS WELL (200x better than no duplex).

FAILURES NOT INDEPENDENT
NOT UNIFORM
INVOLVE CONTROLLERS...
(50x worse than theory)

1985 STATISTICAL BASE

2400 SYSTEMS ~ 10,000 PROCESSORS

~ 40,000 DISCS

9/84 - 6/85 => 1,000 SYSTEM YEARS

=> 5,000 CPU YEARS

=> 20,000 DISC YEARS

166 REPORTED SYSTEM FAILURES

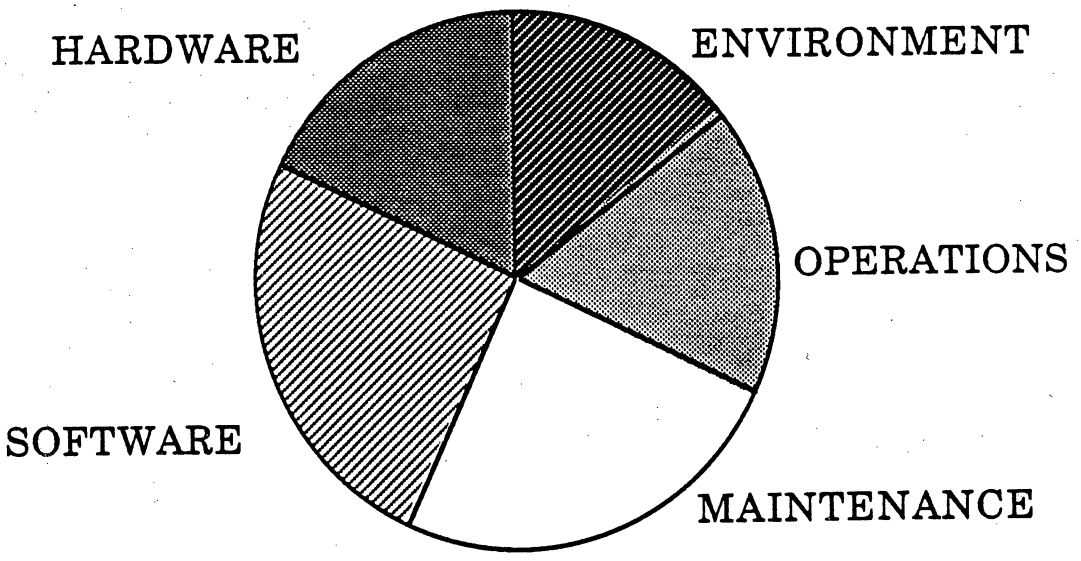
SUBTRACTED INFANT MORTALITY:

	CUSTOMERS
* A NEW BOX:	6
* A NEW PIECE OF SOFTWARE:	2
* SIMPLEX DISCS	2

(2% OF CUSTOMERS HAD 30% OF DOWNS)

107 SYSTEM FAILURES REMAIN

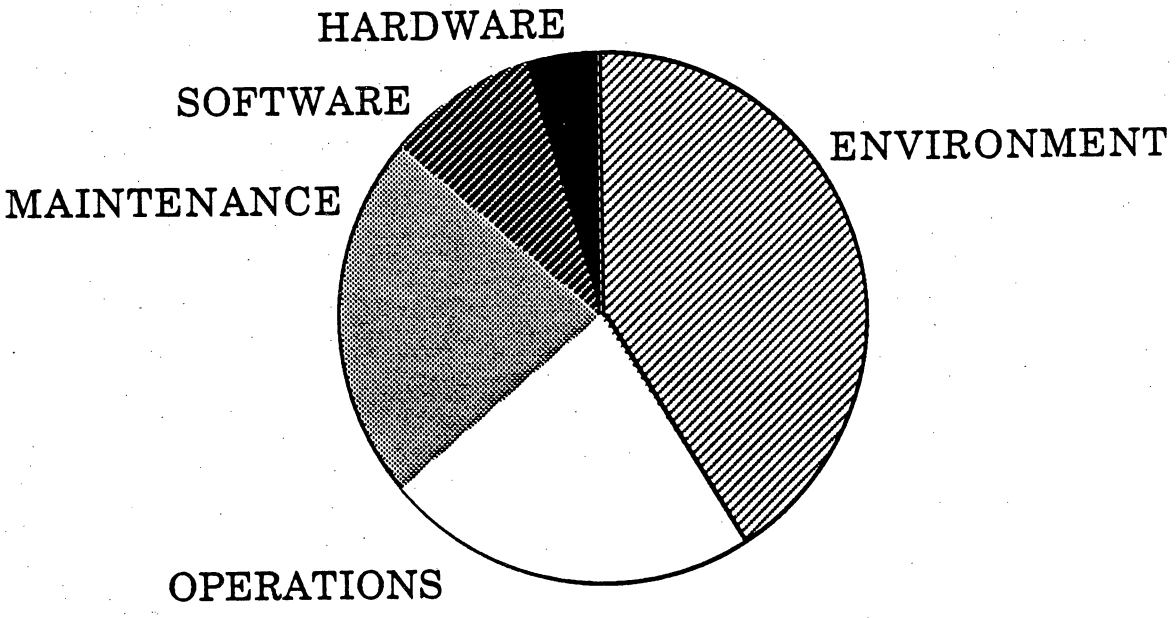
TANDEM EWR DATA



HARDWARE	73 Years
SOFTWARE	50 Years
OPERATIONS	65 Years
MAINTENANCE	50 Years
ENVIRONMENT	87 Years
SYSTEM	11 Years

REMEMBER SYSTEMATIC UNDERREPORTING

BEST GUESS BASED ON FOUR LARGE CUSTOMERS



HARDWARE	~~73 Years~~	50 Years
SOFTWARE	~~50 Years~~	25 Years
OPERATIONS	~~65 Years~~	20 Years
MAINTENANCE	~~50 Years~~	20 Years
ENVIRONMENT	~~87 Years~~	10 Years
SYSTEM	~~11 Years~~	4 Years

WHAT ARE THE CHANCES OF TOLERATING A FAULT

PROCESSOR & DISC RATED AT ~ 10Khr MTBF

	COMPUTED SINGLE FAILURES	OBSERVED DOUBLE FAILS	RATIO
=>	10K PROCESSOR FAILS,	14 DOUBLE	~ 1000:1
=>	40K DISC FAILS,	26 DOUBLE	~1000:1

SOFTWARE FAULTS ARE SOFT:

ADAMS: MOST SOFTWARE FAULTS ARE BENIGN

GRAY: PROCESS PAIR EXPERIMENT SHOWED BACKUP TOLERATED 140:1

Mourad's SLAC STUDY: MVS-XA FRR >5:1

Adams: "Optimizing Preventative Service of Software Products", IBM J R&D,28.1,1984

Gray: "Why Do Computers Stop", Tandem TR85.7, 1985

Mourad: "The Reliability of the IBM/XA Operating System", 15 ISFTCS, 1985.

1987 STATISTICAL BASE

1300 CUSTOMERS

6000 SYSTEMS ~ 16,000 PROCESSORS

~ 97,000 DISCS

6/85 - 6/87 => 12,000 SYSTEM YEARS

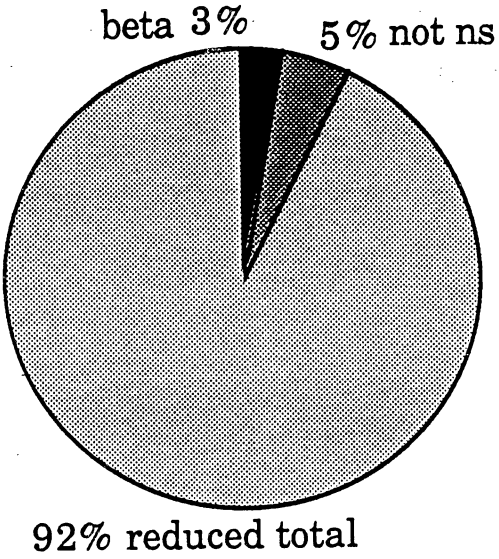
=> 32,000 CPU YEARS

=> 97,000 DISC YEARS
48,000 PAIR YEARS

490 REPORTED SYSTEM FAILURES

205 CUSTOMERS REPORTED OUTAGES

MOST REPORTS WERE FOR PRODUCTION SYSTEMS



SUBTRACTED:

	REPORTS
* BETA TESTS	16
* SIMPLEX DISCS	23

* ONE CUSTOMER WITH A 2 DAY MTBF!

451 "VALID" OUTAGES REMAIN

SUMMARY OF STATISTICS

5/6 CUSTOMERS REPORTED NO OUTAGE IN 2 YEARS

COMPONENT	MTBF
HARDWARE	140 Years
SOFTWARE	63 Years
OPERATIONS	211 Years
MAINTENANCE	200 Years
ENVIRONMENT	235 Years
SYSTEM	27 Years

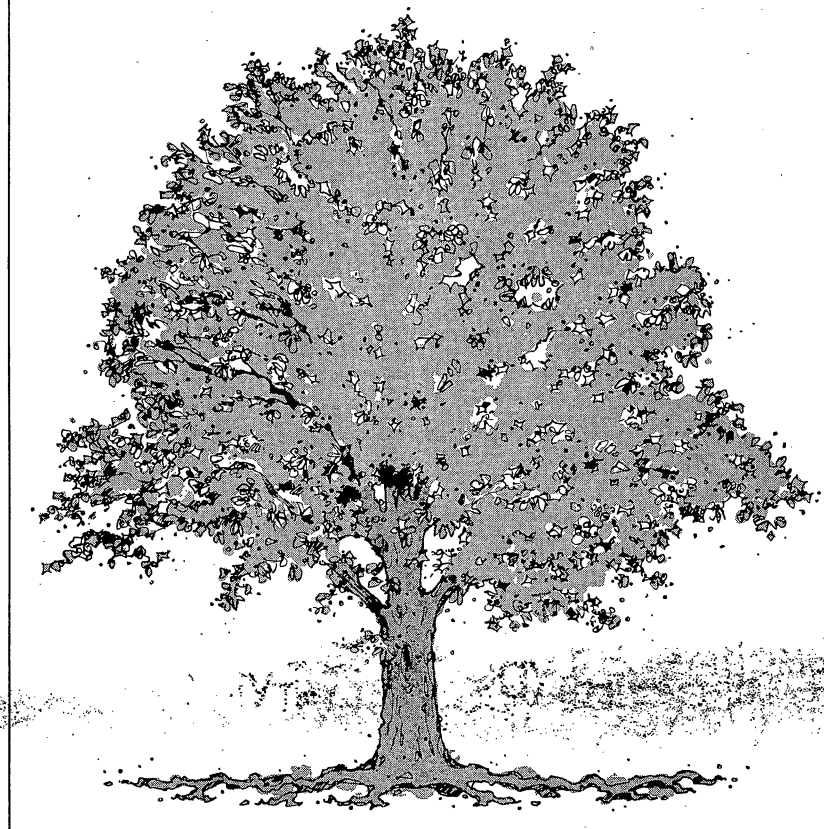
REMEMBER, SYSTEMATIC UNDER-REPORTING OF
OPERATIONS,
MAINTENANCE, &
ENVIRONMENT.

CPU PAIR:	877 Years
DISC PAIR:	1325 Years

Note: introducing a new processor and a new disc drive skewed these statistics

Comment as of Dec. 20th/88

'Tis education forms the common mind;
Just as the twig is bent,
the tree's inclined . . .



Quality Development Program

ENGINEERING QUALITY TECHNOLOGY

DIGITAL's goal of being #1
in customer satisfaction is best achieved through
engineering quality systems. Quality must be an inherent part
of the engineering process. The QDP offers engineers
an integrated program of training and consulting
to help the development of quality systems.

digital

RELIABILITY/AVAILABILITY PROGRAM

DESIGN FOR SYSTEM RELIABILITY

An Integral Part of the
Engineering Quality Technology Education Program

Engineering Quality Technology Group
ZKO2-1/N71
381-1822

This course is based on "The Theory and Practice of Reliable System Design", by D. P. Sieworek and R. S. Swarz, Digital Press, 1982

DESIGN FOR SYSTEM RELIABILITY

This workshop is a fast paced, challenging survey of the state-of-the-art techniques that can be used to design improvements to the reliability of electronic hardware systems, including:

- Attributes, definitions, and theory of reliability
- How hardware and software are designed to enhance reliability
- Modeling to better understand reliability design tradeoffs
- Considerations of design for maintainability
- Field feedback
- Competing commercial architectures

DESIGN FOR SYSTEM RELIABILITY WORKSHOP

Now you can obtain a sound basis for understanding how to design highly reliable electronic systems that are timely, cost effective, and competitive. Attend this intensive, intellectually challenging workshop for practicing design engineers who wish to expand their professional competency. This workshop teaches state-of-the-art practices for producing highly reliable electronic products that can effectively compete in the contemporary and future computer marketplace. Especially offered for engineers with responsibility for designing products or establishing product characteristics, it offers proven, practical techniques, and laboratory experience with design tools, that can be used to cost effectively design in, as well as add on, significant multipliers of product reliability.

COURSE SUMMARY

The course combines lectures with hands-on laboratory exercises using contemporary reliability analysis software with practical Digital examples. Topics covered include:

* Attributes of Reliable Computing and Their Definitions.
  Reasons why reliability is becoming an ever-increasingly important system attribute. Fundamental definitions pertaining to reliable systems. The role of reliability in the design process. Differences between MTBF, Mean Time Between Calls, and Mean Time Between crashes.

* Fundamental Reliability Theory.
  Understanding the sources of faults and their manifestations in systems. The cause-effect sequence of faults. Hardware and software fault handling. Data on faults. Fault prediction models. The stages in fault handling. Developing a taxonomy of reliability enhancement techniques.

* Design for Reliability.
  Examples of translating reliability requirements into system specifications. A survey of fault handling techniques. Evaluation criteria for performing design trade-offs.

* Verification Testing Theory.
  An overview of testing techniques. A brief survey of Design for Testability and Maintainability.

* Commercial Architectures.
  Selected examples from IBM, Univac, Bell Systems, Tandem, Stratus, etc.

AUDIENCE

This course is intended for design engineers, project leaders and others whose responsibility includes developing Digital electronic hardware products. Software engineers developing operating systems or other software that is intimately associated with hardware (such as microcode) may benefit also.

INSTRUCTORS

Dr. Daniel P. Siewiorek, Carnegie-Mellon University (CMU)

Dr. Siewiorek is a professor in the Department of Computer Engineering at CMU, and has been a consultant to Digital for over 12 years, participating in the Reliability, Availability and Maintainability designs for numerous DEC products such as the VAX-11/730, VAX-11/750, VAX 8600, Scorpio, Nautilus, VT-100, and Rainbow.

Dr. Steven Elkind, Digital Equipment Corporation

Steve has been advancing reliability modeling and design for reliability and diagnosability at Digital since 1983. He is now with the SCO Quality and Reliability Advanced Development Group. Previously he was with CSSE RAMP Engineering. He is the author of the Lambda reliability prediction model, and is active in the Design for Test Consortium, the Symptom-Directed Diagnosis Forum, and the Corporate Process Task Force Test Track.

ENROLLMENT INFORMATION: To enroll in this workshop over ENET, set host to node SIVA, username is COURSES, password is COURSES or call DTN 381-1822.

DESIGN FOR SYSTEM RELIABILITY

TABLE OF CONTENTS

1 Attributes of Reliability

2 Why Design for Reliability

3 Faults and their Manifistations

4 Hardware fault prediction

5 System Design

6 Fault Handling Techniques

7 System Specifications

8 Design for Testability & Maintainability

Appendix

Attributes of Reliable Computing and Their Definitions

DESIGN FOR SYSTEM RELIABILITY

1 Attributes of Reliability

OBJECTIVES

* Attributes of Reliable Computing and their definitions
* Reasons why reliability is becoming an ever-increasingly important system attribute
* Fundamental definitions pertaining to reliable systems
* The role of reliability in the design process
* Fault types
* Field data on component failure and system crash rates

Table 1–1. Levels of abstraction for digital computers.

Level	*Sublevel*	*Components*
PMS		Processors
		Memories
		Switches
		Controllers
		Transducers
		Data operators
		Links
Program	High-level language	Software
	ISP	Memory state
		Processor state
		Effective address calculation
		Instruction decode
		Instruction execution
Logic	Register transfer	Data paths
		Registers
		Data operators
		Control
		Hardwired
		Sequential logic machines
		Microprogramming
		Microsequencer
		Microstore
	Switching circuit	Sequential
		Flip-flops
		Latches
		Delays
		Combinatorial
		Gates
		Encoders/Decoders
		Data operators
Circuit		Resistors
		Capacitors
		Inductors
		Power sources
		Diodes
		Transistors

Stages in the development of a system

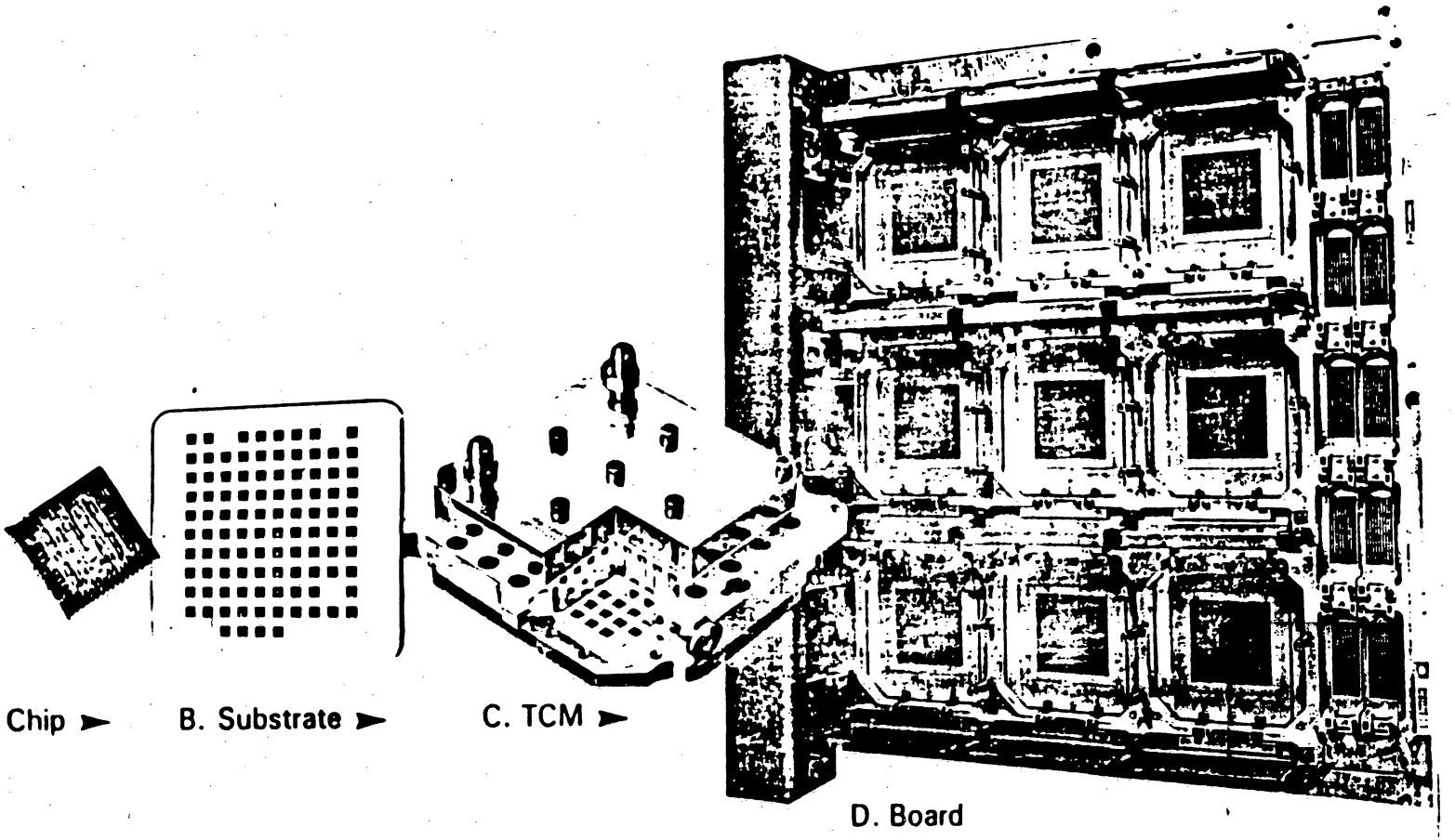
Stage	Error Sources	Error Detection Techniques
Specification and design	Algorithm design Formal specification	Simulation Consistency checks
Prototype	Algorithm design Wiring and assembly Timing Component failure	Stimulus/Response Testing
Manufacture	Wiring and assembly Component failure	System Testing Diagnostics
Intallation	Assembly Component failure	System Testing Diagnostics
Field Operation	Component failure Operator errors Environmental factors	Diagnostics

Hardware - flows through all five stages

Software - first two stages

Problem - the first two stages are done once per product.

Less data available than the last three stages which are done thousands of times per product.


A. Chip
B. Substrate
C. TCM
D. Board

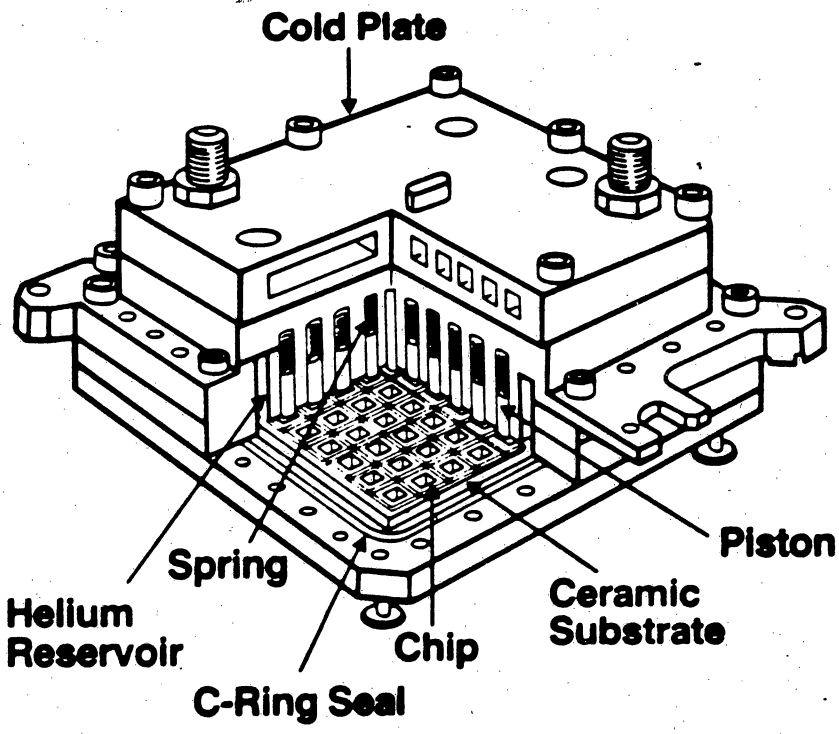
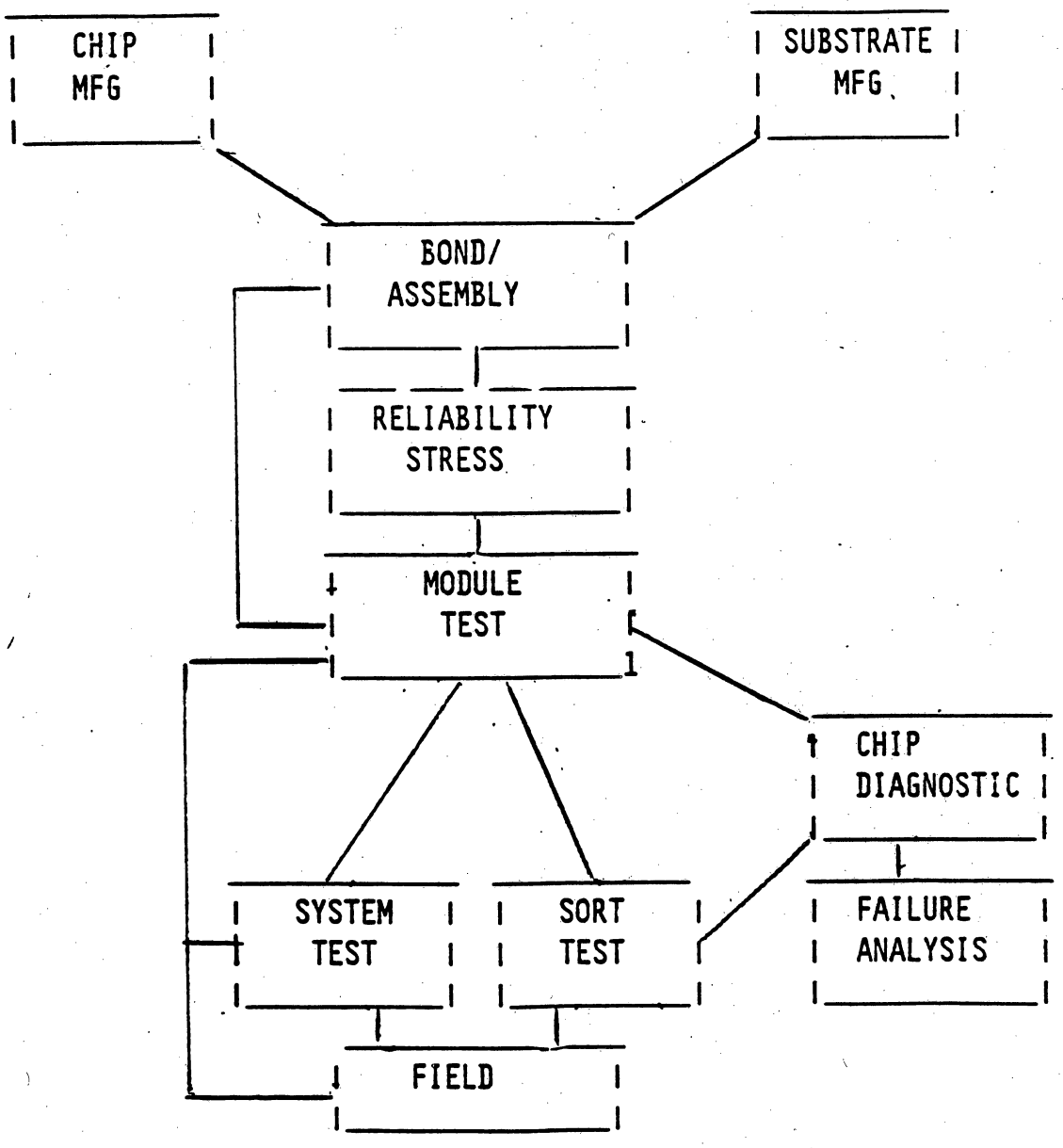


Fig. 1 Thermal Conduction Module (TCM) with water-cooled cold plate

JANUARY 15, 1987

TCM PROCESS FLOW



J. L. PARKER 87006PKM0044 SR

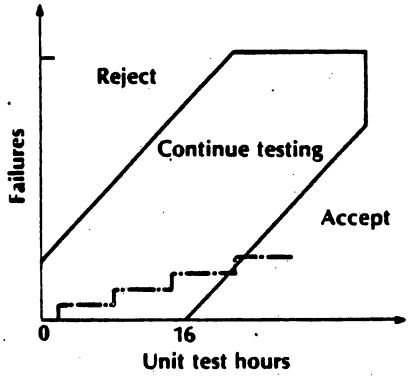


Figure 1–2. Reliability Demonstration Chart for monitoring the progress of a Design Maturity Test.

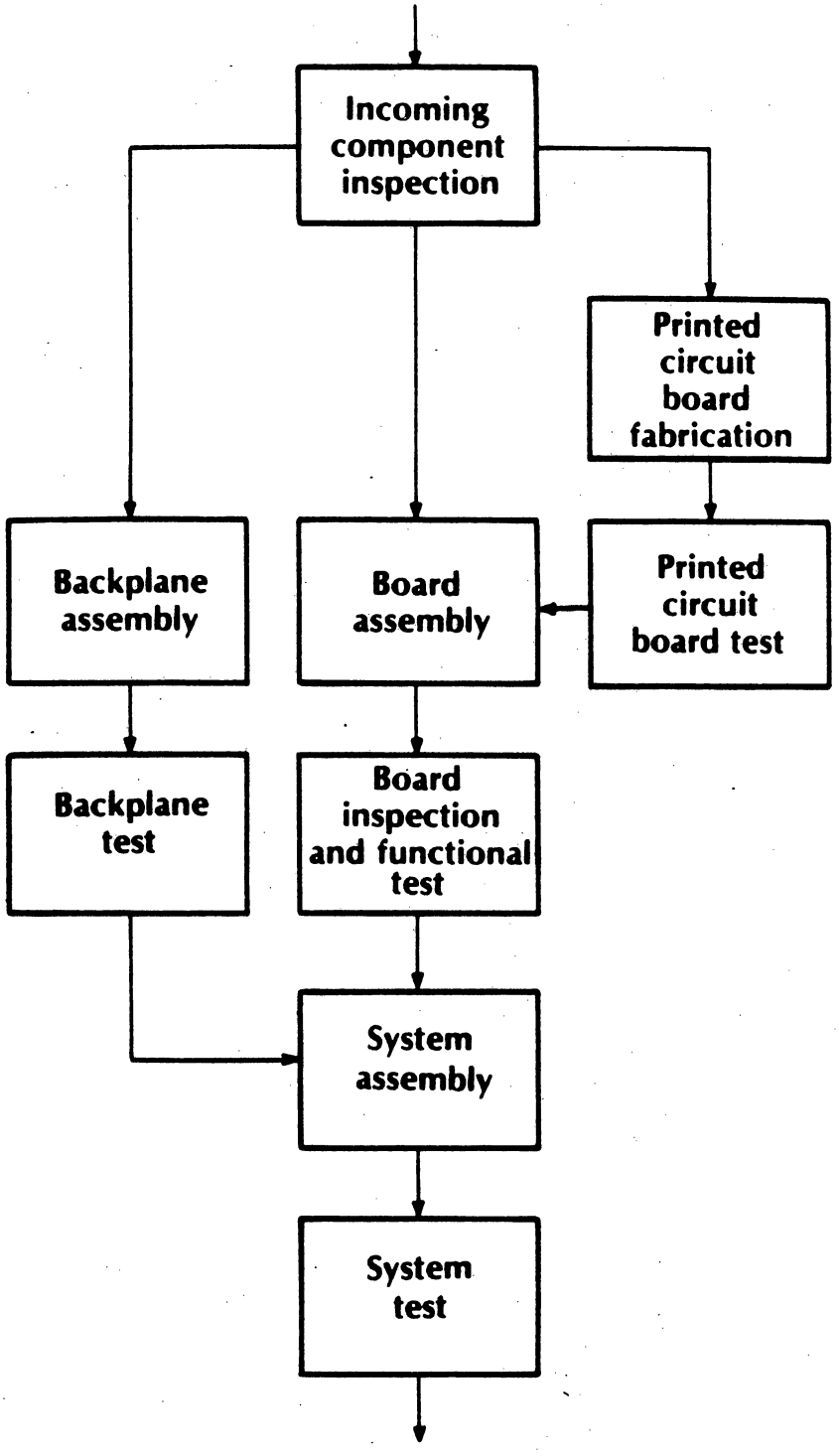


Figure 1–3. Typical steps in the manufacture of a digital system. (© 1979 IEEE.)

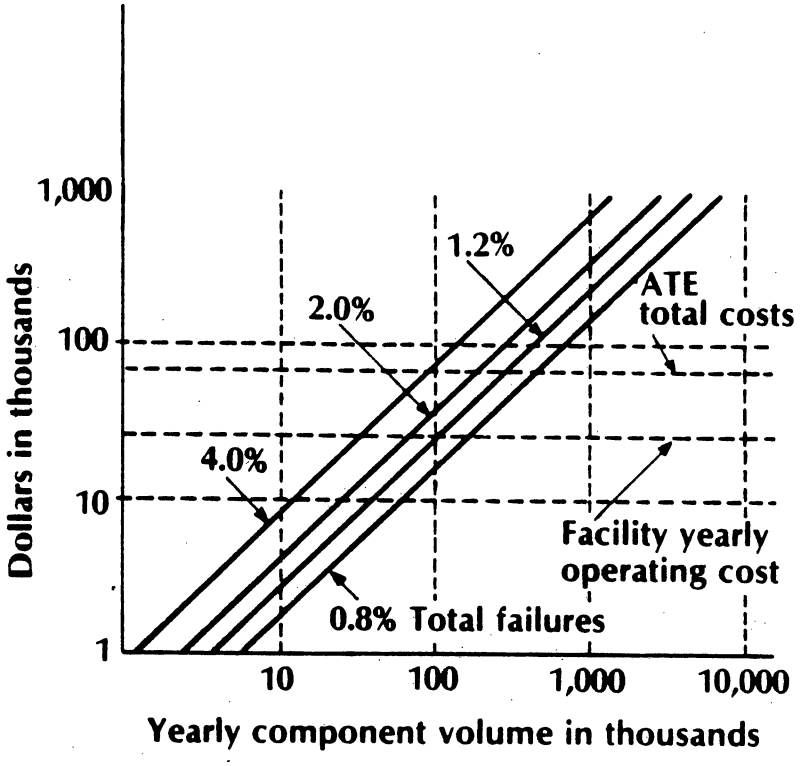


Figure 1–6. Savings from screening and testing as a function of defective component rate and annual device volume.

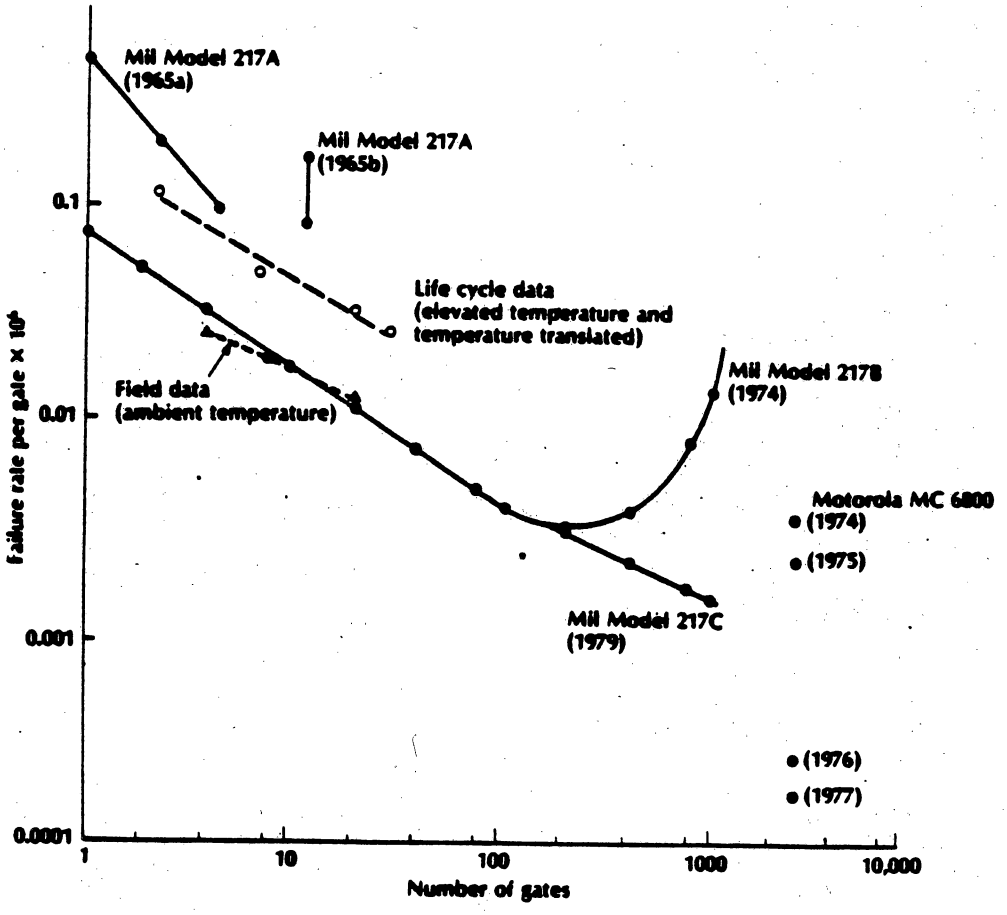


Figure 1–5. Failure rate per gate as a function of chip complexity for bipolar technology.

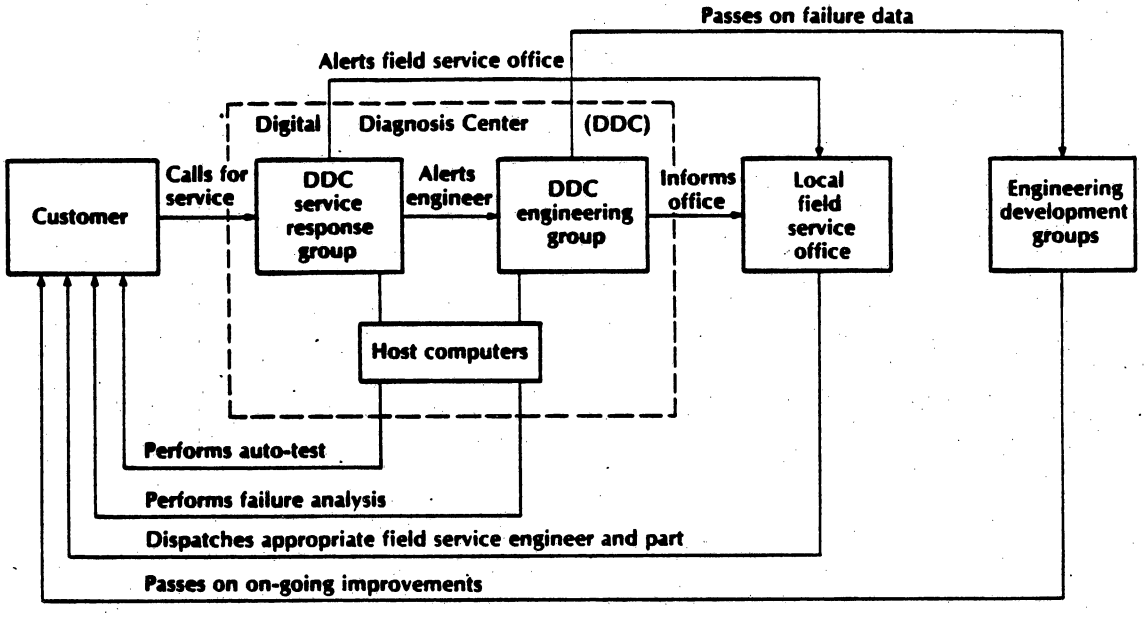


Figure 1–7. Overview of DEC's Remote Diagnosis Network.

Cost of Ownership

$$C = I + \sum_{i=1}^{n} \frac{S_i P_i}{(1+D)^i}$$

S_i - cost of one call

P_i - expected number of failures/year

D - Discount rate

For $S_i = \$300$

$n = 5$

$D = .2$

$$C = I + 7.86\lambda$$

λ in fpmh

RELIABILITY: SURVIVAL PROBABILITY

When repair is costly or a critical function

AVAILABILITY: THE FRACTION OF TIME A SYSTEM MEETS ITS SPECIFICATION

When service can be delayed or denied

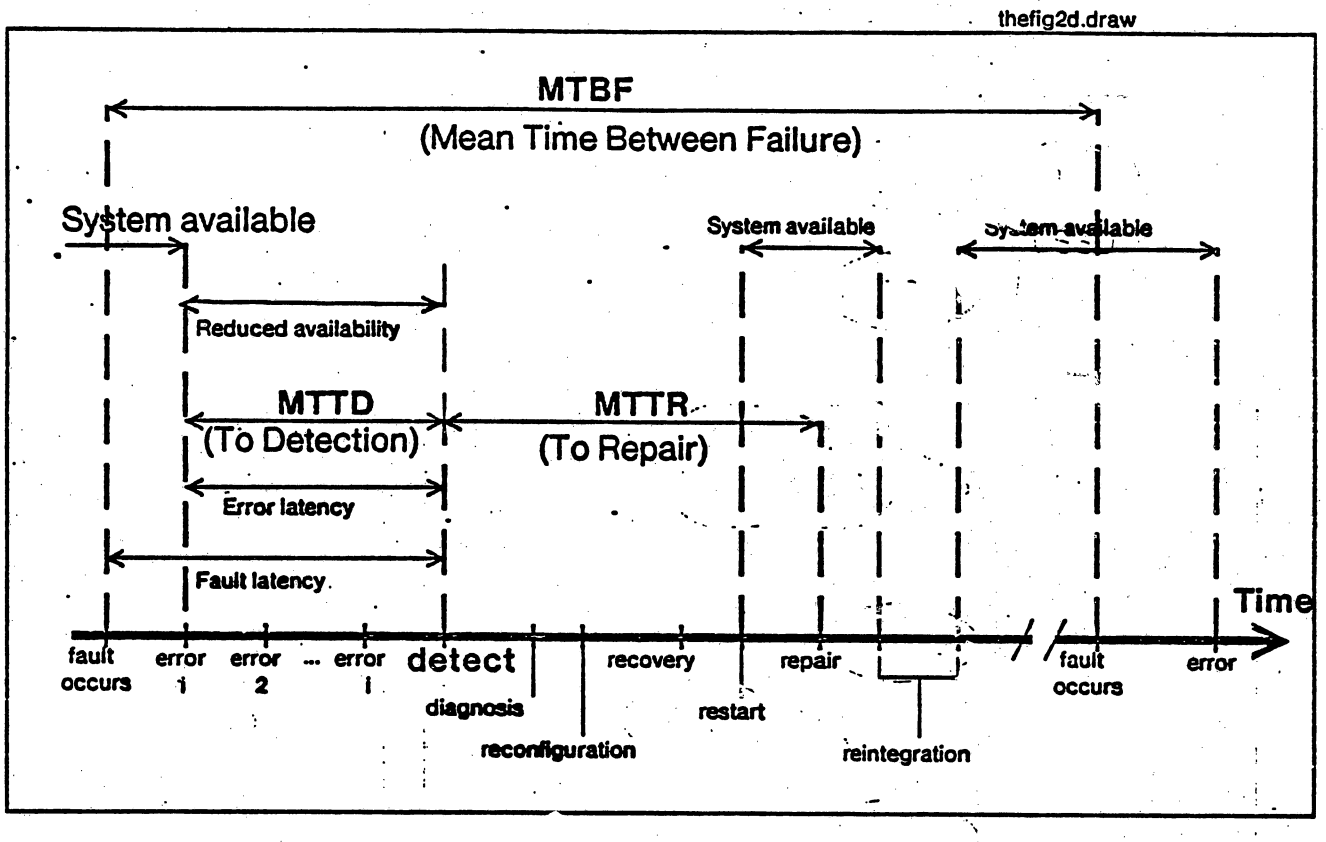
Try to find out how do systems fail

Redundancy: Extra hardware, software, time

Basic Functions:

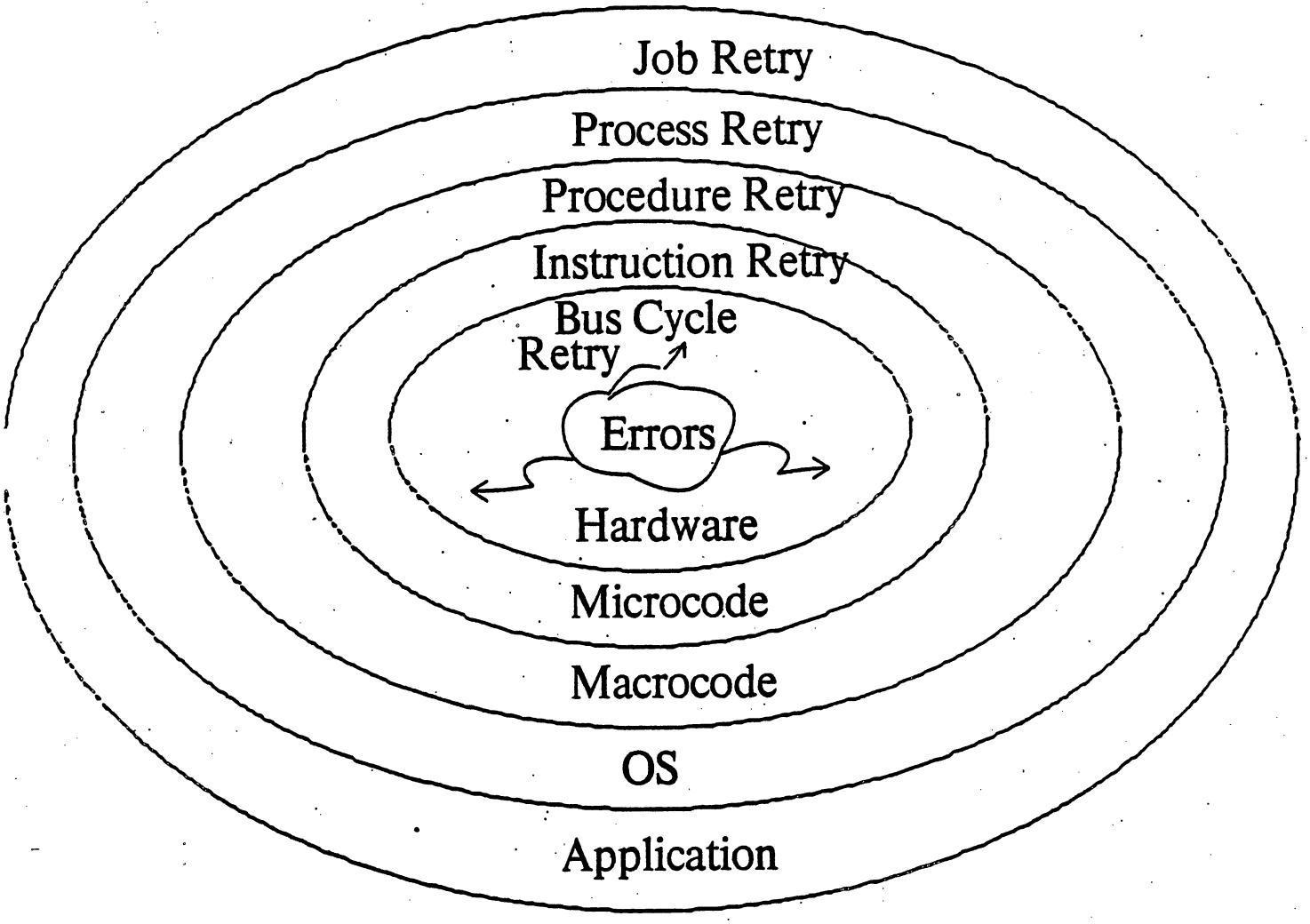
- Fault Confinement
- Fault Detection
- Fault Masking
- Retry
- Diagnosis
- Reconfiguration
- Recovery
- Restart
- Repair
- Reintegration

Error History



Levels in a System

. Detect errors early - limit damage
. Correct at lowest possible level - limit recovery complexity



The further out the error propagates, the more state that is involved and the more diverse error manifestations, and the more complex the error recovery.

Table 1–3. Parameters a designer can control, their impact on system design goals, and typical techniques used to achieve these goals.

Designable Parameters	*Goals*	*Example Techniques*
	Hard Failures	
MTTF	Tolerate	Replication
MTTR	Isolate	Detection
	Transient Faults	
MTTC	Tolerate	Detection/Retry

Hardware Error Tolerance

Advantages

- simplifies recovery for SW end user applications
- saves time
- provides transparency to the user
- decreases MTTR
- increases MTTF, MTTE, MTTC
- error detection logic can help isolate design errors so that future implementations are even more reliable.

Why Design for Reliability

DESIGN FOR SYSTEM RELIABILITY

2 Why Design for Reliability

OBJECTIVES

* Understanding reasons why we need to design reliability into our products

WHY RELIABILITY?

Three of the driving factors:

Critical Applications

- computer outage or error can cause loss of money, time, life.
- no longer just in aerospace, but in more mundane applications.

Increasing System Complexity

- more components ⟶ more likelihood of failure (counter: increased rel. of ↑ LSI).
- lower signal/noise ratios in ↑ LSI speed ⟶ more likelihood of transient errors.
- diagnosis more difficult, downtime is longer, repair costs ↑, increased inventory costs, too.

Relative Cost is Less

AVAILABILITY EXAMPLE

Availability

90 minutes downtime per week 0.991

Reservation system -- $36,000 / minute down

$3.24 million per week

.1% availability = 10 minutes

= $360,000.00

Faults and Their Manifestations

DESIGN FOR SYSTEM RELIABILITY

3 Faults and their Manifistations

OBJECTIVES

* The cause-effect sequence of faults
* Fault Avoidance
* Fault Detection and tolerance
* Hardware and software fault handling
* Data on faults
* Fault prediction models

CAUSE-EFFECT SEQUENCE

FAILURE - Physical change in hardware

FAULT - Deviation of logic function from design value

Hard, Transient

ERROR - Manifestation of a fault by incorrect value

FAULT CLASSIFICATION

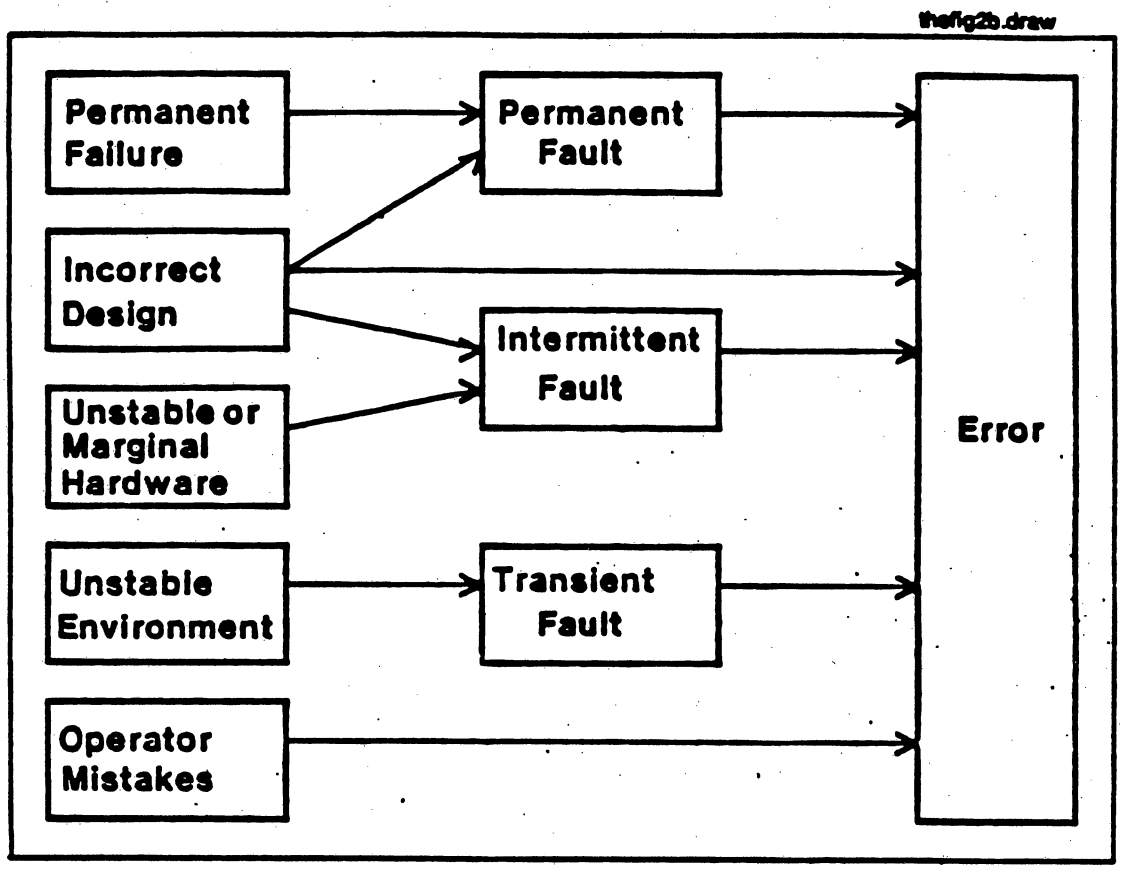
DURATION - Transient - design errors, environment

- Intermittent) Repair by replacement
- Permanent)

EXTENT - Local (independent)
Distributed (related)

VALUE - Determinate (Stuck at X)
Indeterminate (variable)

Definitions:
Sources of Errors



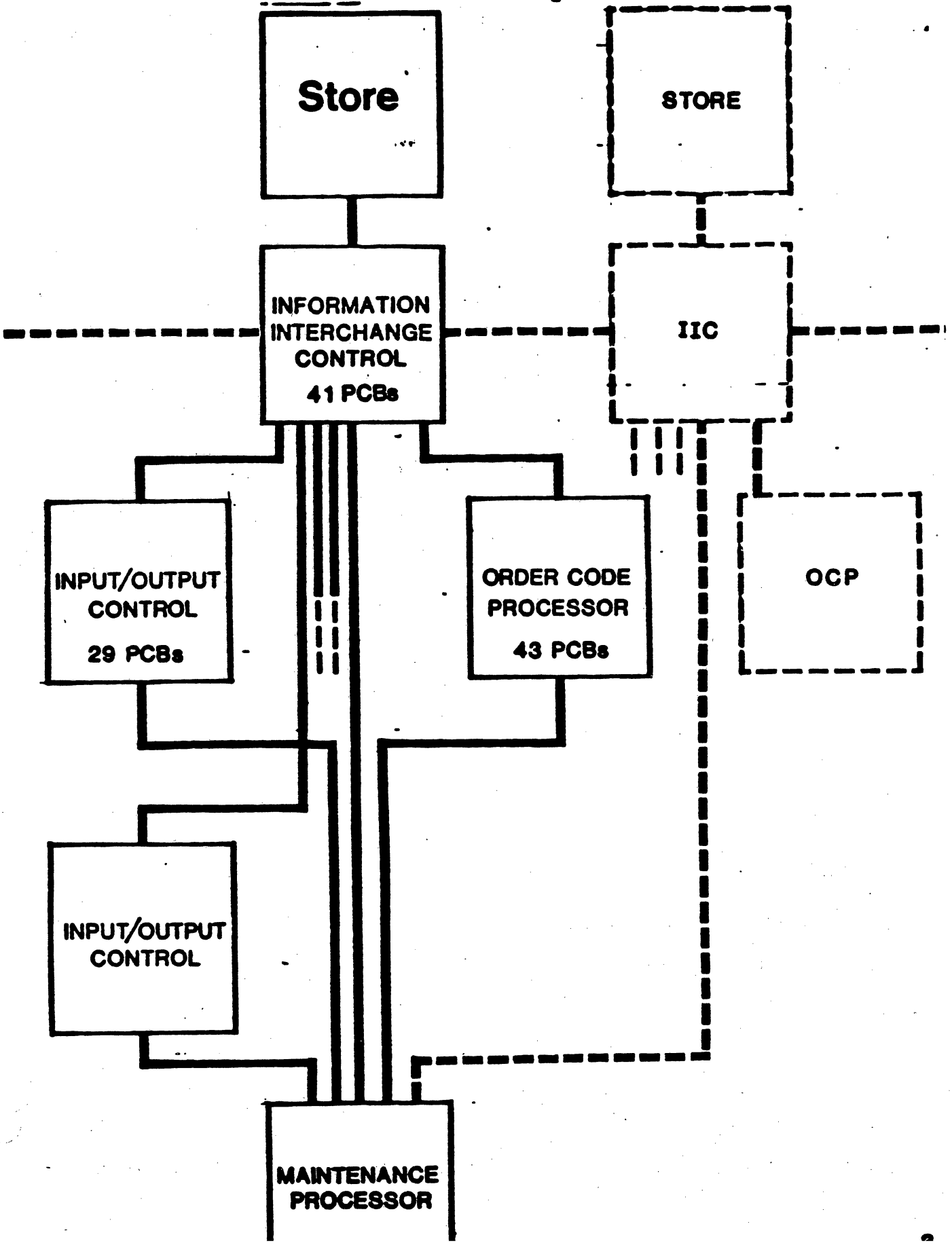
Design environment

Design fault data analysed for:-

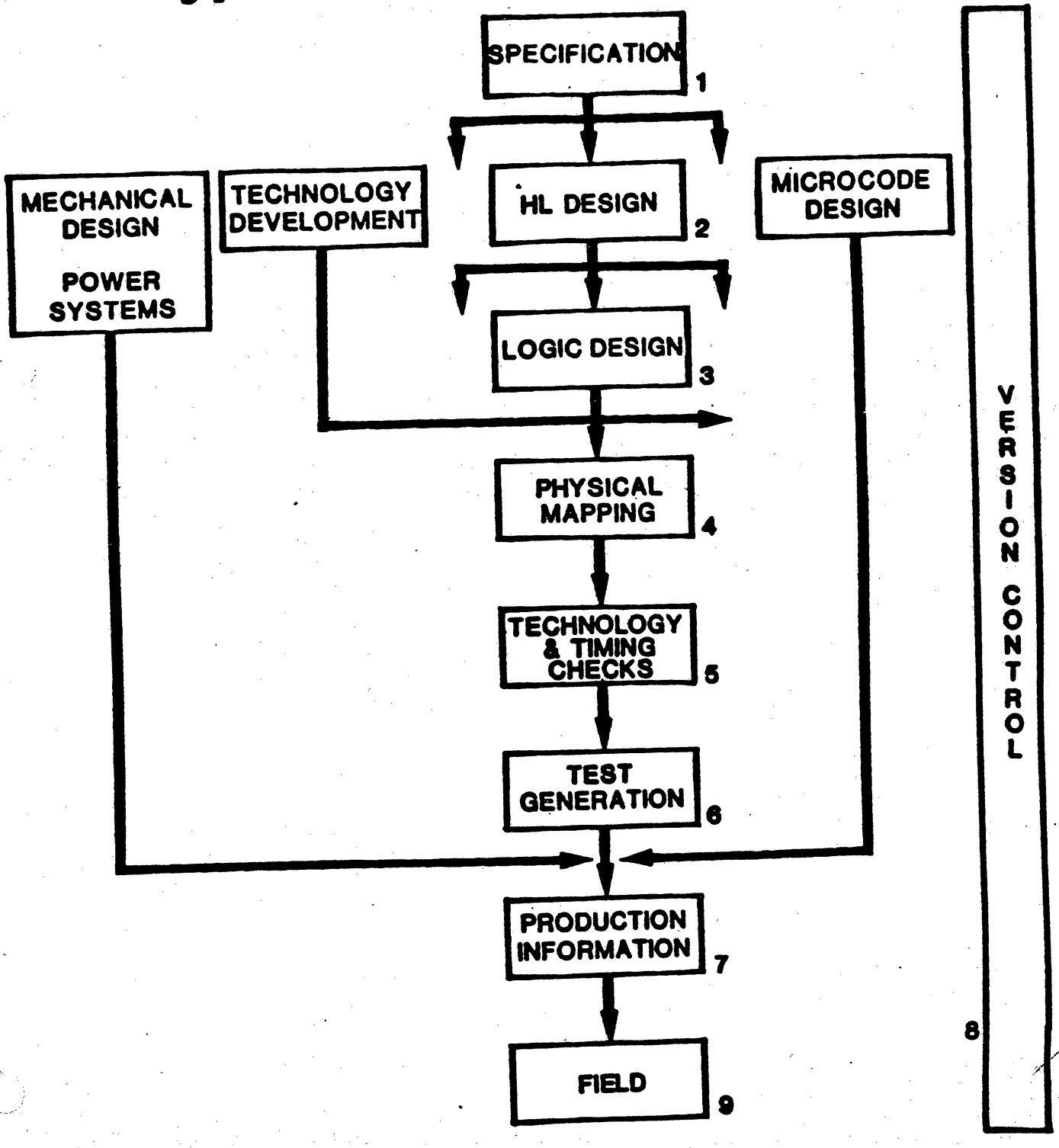
* Mid range mainframe
* Schottky TTL implementaion
* Incremental development
* Extensive design automation
* Design modularity
* Separate module design projects

circa early 1980's

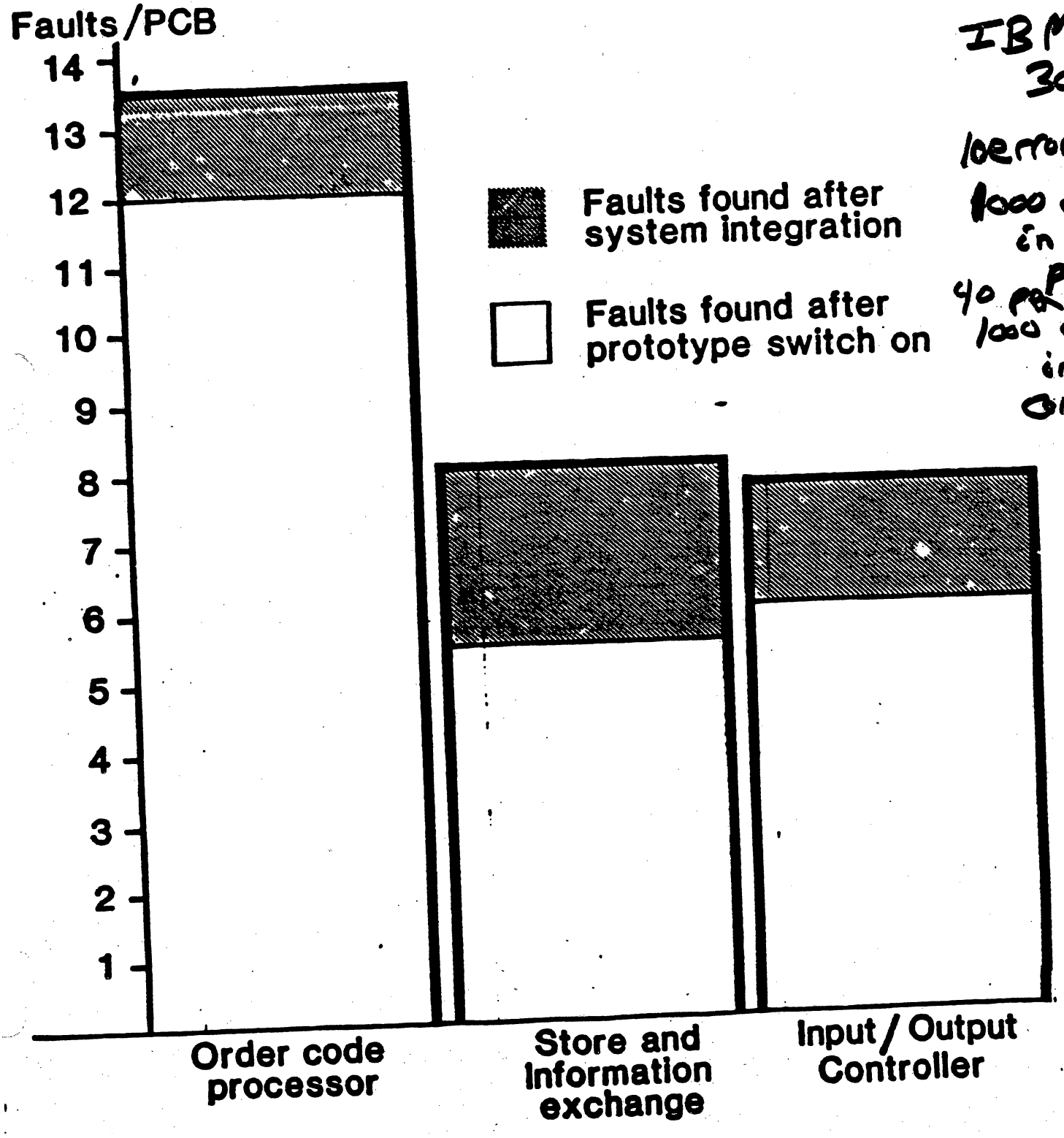
Structure of product



Typical development route



When faults are found



IBM 3081

10error per 1000 circui in data Path

40 per 1000 circuit in control

Fault classification

Specification faults

- Errors
- Ambiguities
- Ommissions

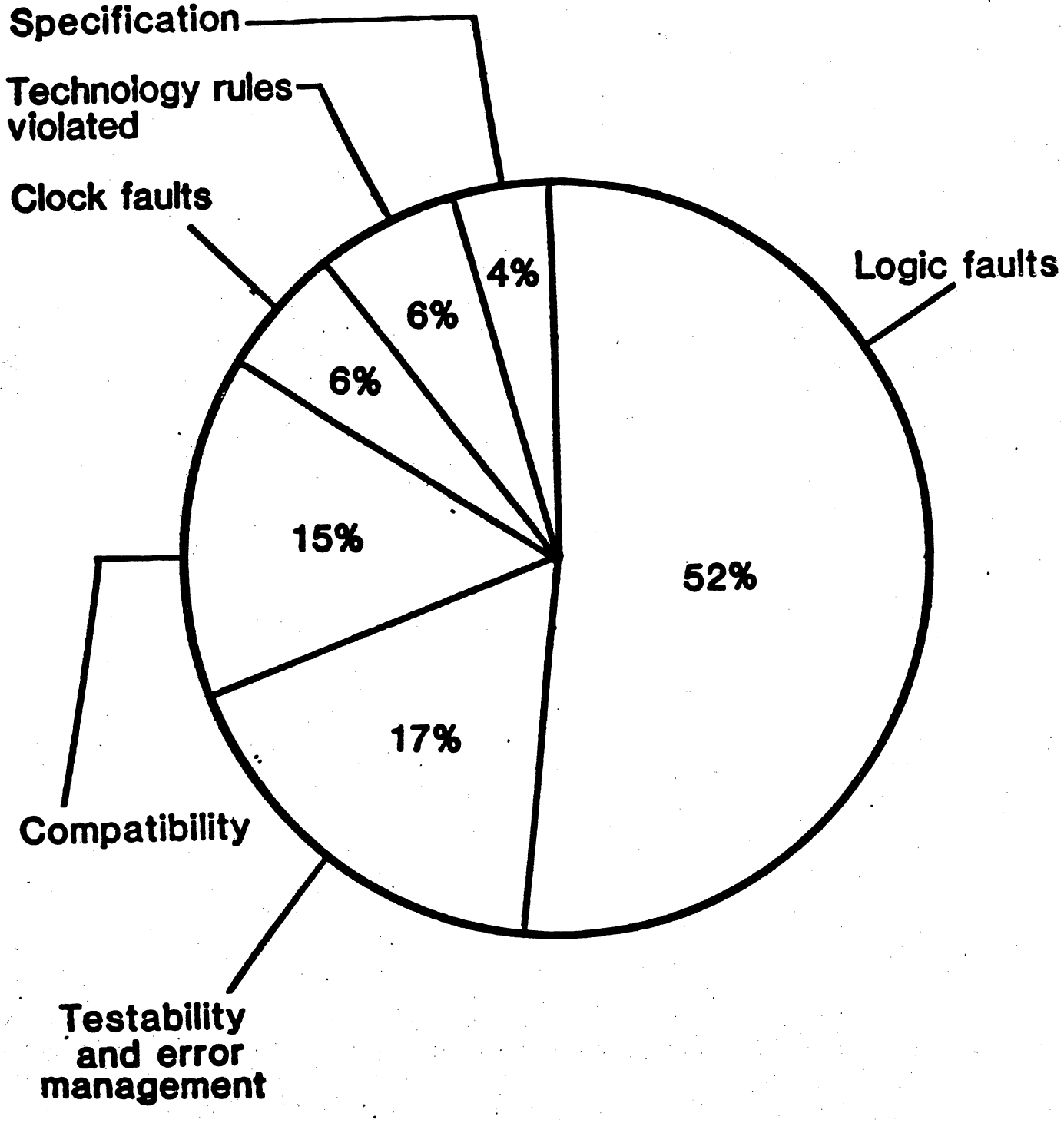
Environment faults

- Technology rules violated
- Noise
- Design Automation errors

Realisation faults

- Simple logic error
- Concurrency problem
- Time out
- Initialisation
- Clock fault
- Performance/Size problem
- Error management fault
- Testability/Maintainability
- Compatability

Breakdown of types of faults found BEFORE system integration



Breakdown of types of faults found AFTER system integration

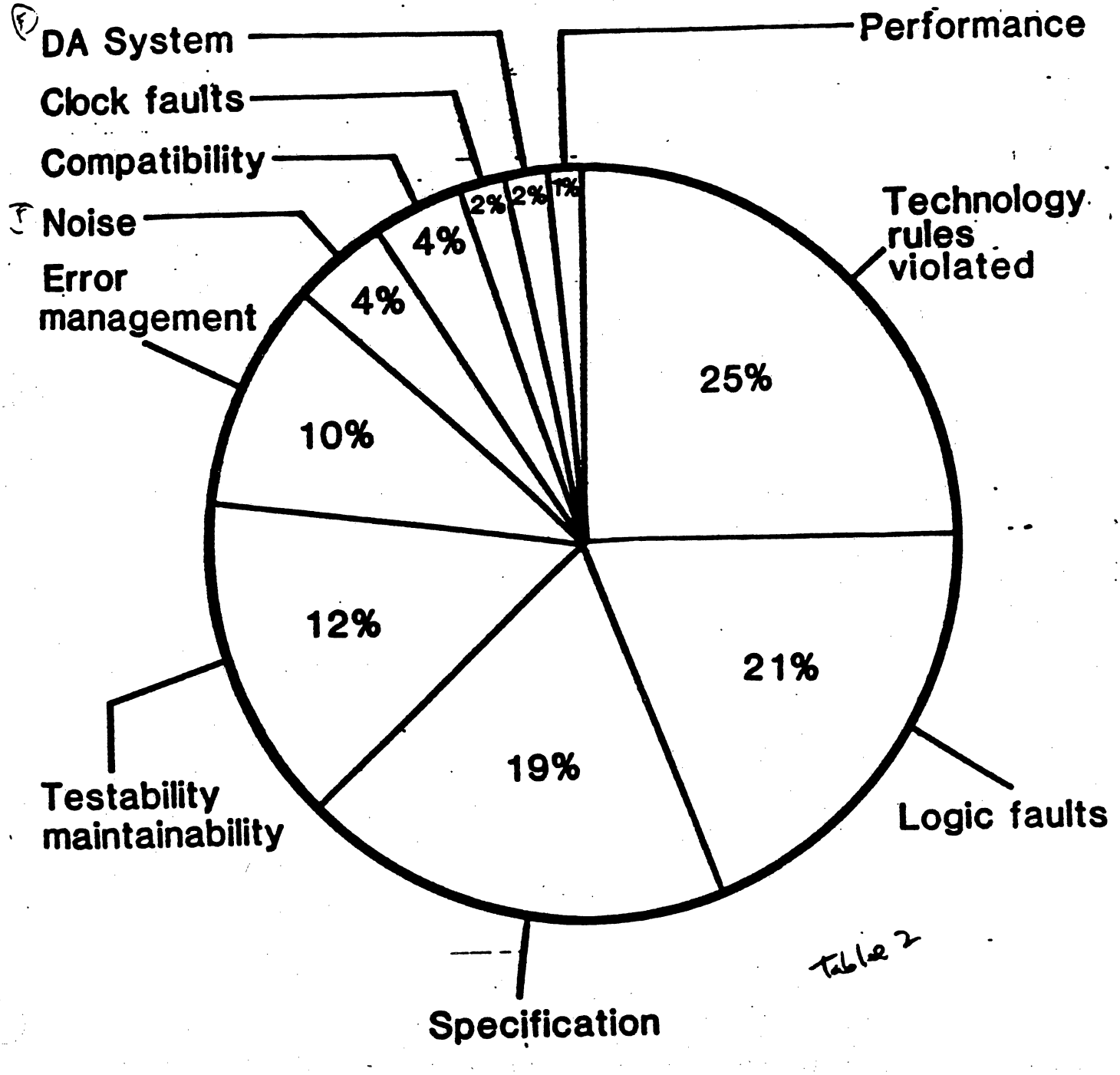


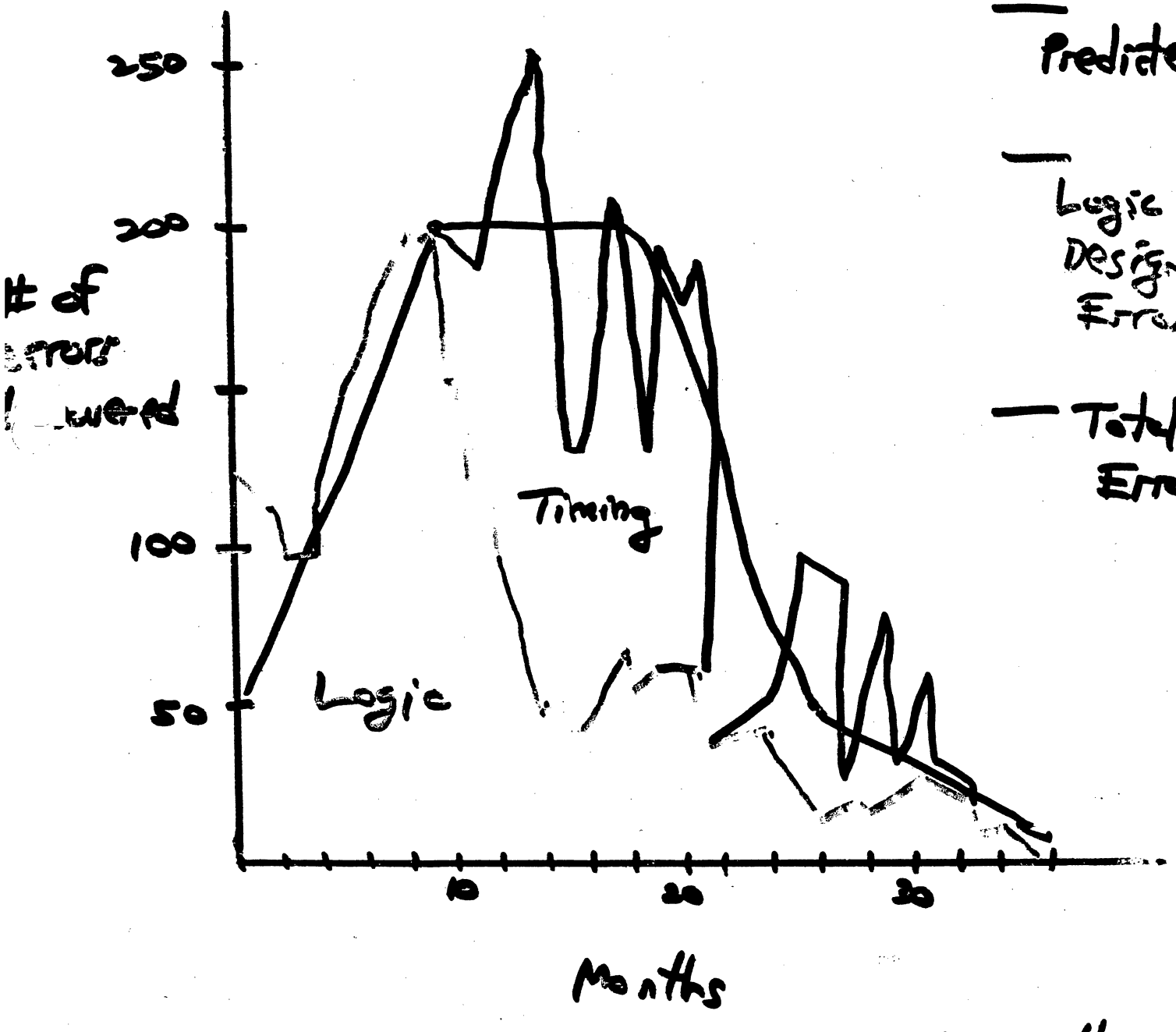
Table 2

Coverage

History

95% error free

- 90% single
- 70% double
- 40% triple decision path



10 errors/1000 circuits - data path

40 errors/1000 circuits - control

Summary of Interrupts:

Intrpt No.	Assignment/ Function	Mode/ Effect
8	unassigned	
9	unassigned	
A	Arithmetic Overflow[1]	USER/Stalls system PRIV/No effect
B	IPC interrupt	
C	Interval timer	
D	Write Protection Violation[1]	USER/Stalls system PRIV/Write protection ignored
E	Page Fault	Still being evaluated
F	Test Adaptor[4]	
10	Halt Instruction Execution[1]	
11	Illegal Opcode[1]	USER/stalls system PRIV/ignored
12	Stack Overflow[1]	USER/stalls system PRIV/ignored
13	Non-local Search Fault[1,2,4]	
14	Privileged instr Fault[1,2]	USER/stall system
15	pmcall fault[1,3]	USER/No Privileged mode routines
16	unassigned	
17	unassigned	
•	Divide exception[5]	USER or PRIV/Stalls system.

Many of the interrupts do not have a proper interrupt handler:

- Arithmetic Overflow
- Write Protection Violation
- Illegal Opcode
- Stack Overflow
- Non-local Search Fault
- Privileged Instruction Violation
- Privileged Mode Call Fault

Use in USER Mode crashes machine.

In addition, there is no interrupt vector for Divide Exception.

To avoid stalling the system due to interrupts, all application software in run in PRIVILEGED mode (interrupts ignored).

QUESTIONS ABOUT FAULTS

- How often do they occur?
- How do they manifest themselves?
- What is the shape of the function?
- What are the parameters of the function?
- What are the meanings of related events?

Trend analysis

Feb 1987

SUMMARY INFORMATION - DEV# 1 TO DEV# 434 8702

CLASS	MODEL	VENDOR	QTY	USE	MOS	U/HF	U/HF	USERS	DEVICE
XSTG	3091	IBM	2	1392	6	999999	999999	2	1
XSTG	3092	IBM	67	45816	6	9999999	9999999	67	2
XSTG	3094	IBM	33	23376	4	9999999	9999999	33	3
CORE	A500	NAS	1	720	6	3240	720	1	4
CORE	A600	NAS	2	1440	6	999999	999999	2	5
CORE	A700	NAS	3	2016	6	9999999	9999999	3	6
CORE	A800	NAS	4	2880	6	9999999	9999999	4	7
CORE	A900	NAS	18	12988	6	9999999	9999999	18	8
CORE	A907	NAS	10	7090	6	13176	9999999	10	9
CORE	XL60	NAS	3	2112	5	9288	9999999	3	10
CORE	XL80	NAS	1	720	4	999999	9999999	1	11
CORE	3031	IBM	2	967	6	9999999	9999999	2	12
CORE	3032	IBMINT	1	720	6	2160	9999999	1	13
CORE	3032	IBMLOC	1	720	6	999999	9999999	1	14
CORE	3033	IBM	51	34734	6	5328	4962	51	15
CORE	3033	IBMCOM	1	672	6	4344	999999	1	16
CORE	3033	IBMINT	1	642	6	4022	9999999	1	17
CORE	3033	IBMSOR	2	1440	6	999999	9999999	2	18
CORE	3033	IBMSTC	2	1440	6	1320	720	2	19
CORE	3081	IBM	359	249299	6	10719	8309	359	20
CORE	3081	IBMCAM	1	720	6	999999	999999	1	21
CORE	3081	IBMSOR	1	720	1	9999999	9999999	1	22
CORE	3083	IBM	101	70022	6	27786	35011	101	23
CORE	3083	IBMCDC	1	720	5	999999	999999	1	24
CORE	3084	IBM	232	160862	6	3928	3217	232	25
CORE	3091	IBM	37	25832	6	17245	25832	37	26
CORE	3092	IBM	236	164717	6	12096	8235	236	27
CORE	3094	IBM	60	42360	4	5052	4706	60	28
CORE	3158	IBM	1	700	6	999999	999999	1	29
CORE	3168	IBM	1	348	5	9999999	9999999	1	30
CORE	4341	IBM	54	38462	6	103895	9999999	54	31
CORE	4341	IBMCMP	1	720	5	5040	9999999	1	32
CORE	4341	IBMLOC	1	720	6	8640	9999999	1	33
CORE	4341	IBMSOR	4	2880	5	999999	9999999	4	34
CORE	4341	IBMSYS	2	414	2	9999999	9999999	2	35
CORE	4341	IPL	6	4200	6	1038	300	6	36
CORE	4361	IBM	3	2112	6	8136	999999	3	37
CORE	4381	IBM	103	71051	6	95066	9999999	103	38
CORE	4381	IBMCMP	1	720	3	2160	9999999	1	39
CORE	4706	AMD	3	2070	6	2431	2070	3	40
CORE	4707	AMD	10	6434	6	4645	2144	10	41
CORE	4708	AMD	27	18414	6	2304	3682	27	42
CORE	4708	AMDPCC	2	1440	5	999999	999999	2	43
CORE	5860	AMD	83	57344	6	20445	9999999	83	44
CORE	5870	AMD	45	31672	6	21076	31672	45	45
CORE	5880	AMD	28	19829	6	14655	9914	28	46
CORE	5893	AMD	20	13505	3	999999	999999	20	47
CENT	A500	NAS	1	720	6	1620	9999999	1	48
CENT	A600	NAS	2	1440	6	999999	9999999	2	49
CENT	A700	NAS	3	2016	6	4608	9999999	3	50
CENT	A800	NAS	4	2880	6	999999	9999999	4	51
CENT	A900	NAS	19	13708	6	5841	4569	19	52
CENT	A907	NAS	18	12740	6	35209	999999	18	53
CENT	XL60	NAS	3	2112	5	999999	9999999	3	54
CENT	XL80	NAS	2	1440	4	443	180	2	55
CENT	3031	IBM	2	967	6	6386	967	2	56
CENT	3032	IBM	2	1440	6	999999	999999	2	57
CENT	3033	IBM	57	38904	6	6350	4863	57	58
CENT	3033	IBMCOM	1	672	6	999999	999999	1	59
CENT	3033	IBMSOR	2	1440	6	9999999	9999999	2	60
CENT	3042	IBM	5	3323	6	9999999	9999999	5	61
CENT	3081	IBM	707	491154	6	132889	122788	707	62
CENT	3081	IBMSOR	2	1440	1	999999	999999	2	63
CENT	3083	IBM	106	74122	6	220169	74122	106	64
CENT	3083	IBMCDC	1	720	5	999999	999999	1	65
CENT	3084	IBM	874	606264	6	104044	75783	874	66
CENT	3091	IBM	38	26552	6	31800	26552	38	67
CENT	3092	IBM	464	324558	6	79526	162279	464	68
CENT	3094	IBM	216	152832	4	95484	76416	216	69

CENT 3158	IBM	2	1400	6	1480	1400	2	70
CENT 3168	IBM	1	348	5	4107	999999	1	71
CENT 4341	IBM	60	42782	6	6776	10695	60	72
CENT 4341	IBMCMP	1	720	5	8640	999999	1	73
CENT 4341	IBMSYS	2	414	2	999999	9999999	2	74
CENT 4341	IPL	6	4200	6	847	247	6	75
CENT 4361	IBM	3	2112	6	999999	999999	3	76
CENT 4381	IBM	134	92999	6	20636	30999	134	77
CENT 4381	IBMCMP	1	720	3	999999	999999	1	78
CENT 4706	AMD	3	2070	6	9726	9999999	3	79
CENT 4707	AMD	10	6434	6	12388	6434	10	80
CENT 4708	AMD	28	18941	6	8938	6313	28	81
CENT 4708	AMDPCC	2	1440	5	999999	999999	2	82
CENT 5860	AMD	84	58064	6	10576	11612	84	83
CENT 5870	AMD	90	63344	6	13959	15836	90	84
CENT 5880	AMD	58	41083	6	8800	8216	58	85
CENT 5893	AMD	39	26390	3	55430	26390	39	86
CHAN A500	NAS	6	4320	6	1254	999999	6	87
CHAN A600	NAS	14	10080	6	40452	10080	14	88
CHAN A700	NAS	24	16128	6	11568	999999	24	89
CHAN A800	NAS	64	46080	6	240840	46080	64	90
CHAN A900	NAS	324	234112	6	108582	46822	324	91
CHAN A907	NAS	256	181296	6	348744	181296	256	92
CHAN XL60	NAS	80	55296	5	132288	999999	80	93
CHAN XL80	NAS	64	46080	4	184320	9999999	64	94
CHAN 2860	IBM	2	1020	6	19840	1020	2	95
CHAN 2870	IBM	13	8174	6	4025	8174	13	96
CHAN 2880	IBM	67	43186	6	37474	43186	67	97
CHAN 3031	IBM	12	5802	6	12772	999999	12	98
CHAN 3032	IBM	12	8640	6	30240	8640	12	99
CHAN 3033	IBM	768	523874	6	12192	14552	768	100
CHAN 3033	IBMCOM	16	10752	6	17376	999999	16	101
CHAN 3033	IBMSOR	32	23040	6	999999	9999999	32	102
CHAN 3042	IBM	18	12384	6	36288	12384	18	103
CHAN 3081	IBM	8248	5722160	6	159597	260098	8248	104
CHAN 3081	IBMSOR	24	17280	1	999999	999999	24	105
CHAN 3083	IBM	1522	1060928	6	323796	1060928	1522	106
CHAN 3083	IBMCDC	16	11520	5	999999	999999	16	107
CHAN 3083	IBMDAT	16	11520	1	9999999	9999999	16	108
CHAN 3084	IBM	10281	7099872	6	393829	507133	10281	109
CHAN 3091	IBM	798	555296	6	227444	185098	798	110
CHAN 3092	IBM	9010	6311208	6	253745	332168	9010	111
CHAN 3094	IBM	4232	2992320	4	413973	374040	4232	112
CHAN 3094	IBMDAT	48	34560	1	999999	999999	48	113
CHAN 3158	IBM	6	4200	6	9402	4200	6	114
CHAN 4341	IBM	341	242784	6	999999	999999	341	115
CHAN 4341	IBMCMP	6	4320	5	51840	9999999	6	116
CHAN 4341	IBMSYS	12	2484	2	999999	9999999	12	117
CHAN 4341	IPL	36	25200	6	4293	2100	36	118
CHAN 4361	IBM	16	11232	6	20088	999999	16	119
CHAN 4381	IBM	1153	803970	6	318459	803970	1153	120
CHAN 4381	IBMCMP	5	3600	3	999999	999999	5	121
CHAN 4706	AMD	39	27090	6	59246	9999999	39	122
CHAN 4707	AMD	112	69344	6	39302	69344	112	123
CHAN 4708	AMD	424	289372	6	60808	26306	424	124
CHAN 4708	AMDPCC	32	23040	5	999999	999999	32	125
CHAN 5860	AMD	1656	1140060	6	211454	103641	1656	126
CHAN 5870	AMD	1522	1075400	6	146291	268850	1522	127
CHAN 5880	AMD	1128	795841	6	758820	999999	1128	128
CHAN 5893	AMD	768	520404	3	999999	9999999	768	129
MASS 3850	IBM	52	7609	6	1	1	48	130
MASS 3850	IBMTLS	1	69	3	1	999999	1	131
MASS 3850	TOTAL	53	7678	6	1	1	49	132
MASS 38500	IBM	64	7491	6	182	170	47	133
MASS 38500	IBMTLS	1	69	3	999999	999999	1	134
MASS 38500	TOTAL	65	7560	6	183	171	48	135
MASS 38501	IBM	120	7609	6	13	18	48	136
MASS 38501	IBMTLS	2	69	3	4	4	1	137
MASS 38501	TOTAL	122	7678	6	13	17	49	138
MASS 38502	IBM	260	1350290	6	304	287	47	139
MASS 38502	IBMTLS	4	18787	3	828	587	1	140

MASS	38502	TOTAL	264	1369078	6	305	289	48	141
MASS	38504	IBM	133	7490	6	5	6	46	142
MASS	38504	IBMTLS	2	69	3	5	3	1	143
MASS	38504	TOTAL	135	7560	6	5	6	47	144
MASS	38508	IBM	174	7490	6	32	36	46	145
MASS	38508	IBMTLS	4	69	3	38	13	1	146
MASS	38508	TOTAL	178	7560	6	32	35	47	147
UNIT	3800	DGX	17	243923	6	5846	5420	9	148
UNIT	3800	IBM	317	4405147	6	6018	7491	146	149
UNIT	3800	IBMCUS	3	33727	5	4824	3372	1	150
UNIT	3800	TOTAL	337	4682797	6	6003	7282	153	151
UNIT	38003	IBM	306	5514269	6	14824	16460	128	152
UNIT	38003	IBMDAT	2	1084	5	8502	999999	1	153
UNIT	38003	TOTAL	308	5515353	6	14774	16463	129	154
DRUM	2305-1	IBM	1	12	2	999999	999999	1	155
DRUM	2305-1	TOTAL	1	12	2	9999999	9999999	1	156
DRUM	2305-2	IBM	18	249	6	197	249	7	157
DRUM	2305-2	TOTAL	18	249	6	197	249	7	158
DRUM	3805	INT	16	308	6	2801	999999	3	159
DRUM	3805	TOTAL	16	308	6	2801	9999999	3	160
DRUM	3864	MEM	42	968	6	4696	9999999	8	161
DRUM	3864	TOTAL	42	968	6	4696	9999999	8	162
DRUM	4305-2	STC	259	4880	6	637	697	40	163
DRUM	4305-2	TOTAL	259	4880	6	637	697	54	164
DISK	33XXS	MEM	17	354286	6	999999	999999	5	165
DISK	33XXS	NAS	38	1419766	6	9999999	9999999	14	166
DISK	33XXS	STC	28	205089	4	184175	9999999	14	167
DISK	33XXS	TOTAL	83	1979142	6	1702256	9999999	33	168
DISK	33301	IBM	192	45508	6	3211	5688	22	169
DISK	33301	IBMMSS	14	29105	6	61126	999999	3	170
DISK	33301	MEM	197	56823	6	5112	6313	12	171
DISK	33301	NAS	65	25664	6	4031	3208	2	172
DISK	33301	NASCMP	165	53996	5	1406	2571	2	173
DISK	33301	TOTAL	633	211097	6	3316	4589	38	174
DISK	333011	CDC	23	2102	6	2223	1051	2	175
DISK	333011	CDCCMP	16	4021	5	869	1340	1	176
DISK	333011	IBM	294	104025	6	3457	3715	30	177
DISK	333011	IBMMSS	89	182124	6	20666	60708	11	178
DISK	333011	IBMQTX	9	11807	5	999999	999999	1	179
DISK	333011	MEM	479	207418	6	6381	8642	21	180
DISK	333011	MEMTLS	8	2078	1	1039	1039	1	181
DISK	333011	NAS	110	39548	6	1088	878	4	182
DISK	333011	NASCMP	52	27415	5	2193	1827	1	183
DISK	333011	TEL	125	75450	6	3101	2357	3	184
DISK	333011	TOTAL	1205	655993	6	4541	4259	64	185
DISK	3340	IBM	43	5207	6	337	473	6	186
DISK	3340	TOTAL	43	5207	6	337	473	6	187
DISK	3344	IBM	8	2265	5	999999	999999	1	188
DISK	3344	TOTAL	8	2265	5	9999999	9999999	1	189
DISK	3350	AMD	4104	3316895	6	120496	97555	49	190
DISK	3350	AMDCMP	16	12710	5	47035	12710	1	191
DISK	3350	CDC	26	25373	6	21467	999999	2	192
DISK	3350	IBM	8879	7952932	6	23261	25737	214	193
DISK	3350	IBMCDC	40	36107	5	19880	36107	1	194
DISK	3350	IBMDAT	55	19292	6	28125	999999	2	195
DISK	3350	IBMMSS	321	449585	6	5850	5690	36	196
DISK	3350	IBMQTX	19	2582	5	18308	999999	1	197
DISK	3350	IBMSOR	157	94089	6	14675	15681	3	198
DISK	3350	MEM	1043	733922	6	28683	24464	37	199
DISK	3350	NAS	7	3936	6	33925	999999	1	200
DISK	3350	NASH	68	26812	6	7347	26812	4	201
DISK	3350	STC	379	284234	6	27990	23686	20	202
DISK	3350	STCICS	50	21289	6	30603	10644	1	203
DISK	3350	TEL	16	9584	6	10126	9584	1	204
DISK	3350	TOTAL	15180	12989348	6	24755	27288	320	205
DISK	3350-2	CDC	1431	998563	6	17341	16642	18	206
DISK	3350-2	CDCCOM	150	32740	6	3973	6548	1	207
DISK	3350-2	MEM	1223	1037687	6	25736	22078	35	208
DISK	3350-2	MEMTLS	16	1643	1	999999	999999	1	209
DISK	3350-2	NASCMP	10	11959	5	9999999	9999999	1	210
DISK	3350-2	NASH	64	109499	6	275826	9999999	3	211

DISK 3350-2	STC	906	411015	6	12826	17125	33	212
DISK 3350-2	STCCUS	22	6568	5	9189	3284	1	213
DISK 3350-2	STCQTX	2	29	1	999999	999999	1	214
DISK 3350-2	TOTAL	3824	2609706	6	19252	18910	91	215
DISK 3375	IBM	120	216539	6	23835	21653	7	216
DISK 3375	IBMCMP	8	777	3	999999	999999	1	217
DISK 3375	IBMSOR	4	255	3	9999999	9999999	1	218
DISK 3375	MEM	4	468	3	9999999	9999999	1	219
DISK 3375	TOTAL	136	218041	6	23992	21804	9	220
DISK 3380	IBM	31055	64908800	6	143577	160665	479	221
DISK 3380	IBMCDC	36	79404	5	19062	26468	2	222
DISK 3380	IBMCES	40	66701	1	999999	999999	1	223
DISK 3380	IBMCMP	2	9439	5	9999999	9999999	1	224
DISK 3380	IBMDAT	88	67091	6	22730	67091	2	225
DISK 3380	IBMSCS	34	57433	2	12653	9572	1	226
DISK 3380	IBMSOR	159	374935	6	100566	999999	3	227
DISK 3380	MEM	514	852950	6	45323	44892	20	228
DISK 3380	MEMUNI	8	9793	1	9793	9793	1	229
DISK 3380	NASCMP	14	58936	5	269139	999999	1	230
DISK 3380	NASH	1138	2725372	6	169617	129779	33	231
DISK 3380	SAN	223	373162	6	88048	93290	8	232
DISK 3380	STC	2851	5716247	6	99465	100285	93	233
DISK 3380	TOTAL	36162	75300272	6	134007	145930	527	234
DISK 3380D	IBM	11171	23369000	6	212006	224701	361	235
DISK 3380D	IBMCDC	36	90827	1	45413	45413	1	236
DISK 3380D	IBMDAT	60	71793	6	437269	999999	2	237
DISK 3380D	IBMSOR	15	46114	6	999999	9999999	2	238
DISK 3380D	NASH	128	223126	6	765962	9999999	4	239
DISK 3380D	TOTAL	11410	23800862	6	213112	224536	366	240
DISK 3380E	IBM	12330	24518664	6	169884	216979	396	241
DISK 3380E	IBMCES	18	31450	1	999999	999999	1	242
DISK 3380E	NASH	511	899375	6	431091	224843	18	243
DISK 3380E	STC	439	770841	6	57712	77084	28	244
DISK 3380E	TOTAL	13298	26220332	6	167098	206459	411	245
DISK 3380H	MEM	252	353745	6	36703	25267	10	246
DISK 3380H	TOTAL	252	353745	6	36703	25267	10	247
DISK 33800	CDC	1023	783563	6	39801	52237	8	248
DISK 33800	CDCCOM	31	23441	6	18036	7813	1	249
DISK 33800	TOTAL	1054	807004	6	38200	44833	9	250
DISK 6380	AMD	4475	3975391	6	130290	107443	64	251
DISK 6380	TOTAL	4475	3975391	6	130290	107443	64	252
DISK 6380E	AMD	120	29732	3	22180	29732	7	253
DISK 6380E	TOTAL	120	29732	3	22180	29732	7	254
DISK 733012	NASCMP	54	22386	6	1911	1599	1	255
DISK 733012	TOTAL	54	22386	6	1369	1599	1	256
TELE 2701	IBM	276	74175	6	5214	3090	4	257
TELE 2701	TOTAL	276	74175	6	5291	3090	4	258
TELE 2701T	IBM	81	17884	6	1848	17884	4	259
TELE 2701T	MEM	2	444	6	1895	999999	2	260
TELE 2701T	TOTAL	83	18329	6	1861	18329	6	261
TELE 2702T	IBM	1	87	5	999999	999999	1	262
TELE 2702T	TOTAL	1	87	5	9999999	9999999	1	263
TELE 2703T	IBM	18	507	6	9999999	9999999	2	264
TELE 2703T	NCR	13	4129	6	75	45	1	265
TELE 2703T	TOTAL	31	4637	6	146	51	3	266
TELE 3174	IBM	19	8916	2	999999	999999	3	267
TELE 3174	TOTAL	19	8916	2	9999999	9999999	3	268
TELE 3178	IBM	891	26232	6	459	610	23	269
TELE 3178	TEL	27	1258	6	1826	1258	1	270
TELE 3178	TOTAL	918	27491	6	470	624	24	271
TELE 3178T	IBM	1	145	6	999999	999999	1	272
TELE 3178T	TOTAL	1	145	6	9999999	9999999	1	273
TELE 3179		34	38797	6	9999999	9999999	1	274
TELE 3179	IBM	688	9507	6	5510	4753	18	275
TELE 3179	TOTAL	722	48304	6	26819	24152	19	276
TELE 3180	IBM	469	7479	6	32771	7479	13	277
TELE 3180	TEL	61	1087	1	999999	999999	1	278
TELE 3180	TOTAL	530	8566	6	33859	8566	14	279
TELE 3272	IBM	120	3543	6	504	442	8	280
TELE 3272	TOTAL	120	3543	6	504	442	8	281
TELE 3274		305	304481	6	999999	999999	8	282

TELE 3274	CCU	7	7335	6	9999999	9999999	3	283
TELE 3274	IBM	1914	2059893	6	243317	294270	122	284
TELE 3274	IBMCDC	1	592	5	999999	999999	1	285
TELE 3274	TOTAL	2227	2372303	6	277351	338900	134	286
TELE 3274T	IBM	7	376	6	999999	999999	1	287
TELE 3274T	TOTAL	7	376	6	9999999	9999999	1	288
TELE 3277		1674	51197	6	297	166	23	289
TELE 3277	CCU	120	1349	6	999999	999999	2	290
TELE 3277	HAR	232	1503	6	9999999	9999999	2	291
TELE 3277	IBM	3319	214481	6	2086	1802	70	292
TELE 3277	IBMCDC	48	619	5	160	154	1	293
TELE 3277	PAR	150	1057	6	353	999999	2	294
TELE 3277	TEL	114	2400	6	2132	800	3	295
TELE 3277	TOTAL	5657	272608	6	818	628	103	296
TELE 3277T		66	6502	6	342	722	4	297
TELE 3277T	CCU	8	363	5	999999	999999	1	298
TELE 3277T	IBM	17	3289	6	12471	9999999	4	299
TELE 3277T	TOTAL	91	10155	6	886	1128	9	300
TELE 3278		2175	44616	6	2467	2624	28	301
TELE 3278	CCU	1	1667	5	999999	999999	1	302
TELE 3278	IBM	9760	501528	6	2595	3949	137	303
TELE 3278	IBMCDC	38	455	5	622	455	1	304
TELE 3278	LEE	88	1253	6	999999	999999	1	305
TELE 3278	MEM	277	5465	6	129	105	4	306
TELE 3278	TEL	135	6325	6	3566	3162	3	307
TELE 3278	TOTAL	12474	561313	6	2417	2820	174	308
TELE 3278T		59	884	6	95	29	2	309
TELE 3278T	IBM	113	1311	6	978	437	5	310
TELE 3278T	TOTAL	172	2195	6	268	66	7	311
TELE 3279		210	3724	6	999999	999999	4	312
TELE 3279	IBM	1430	90407	6	23529	90407	53	313
TELE 3279	IBMCDC	4	45	5	170	45	1	314
TELE 3279	TOTAL	1644	94177	6	23824	47088	58	315
TELE 3290	IBM	177	4060	6	2081	4060	17	316
TELE 3290	TOTAL	177	4060	6	2081	4060	17	317
TELE 3704	IBM	19	450	5	999999	999999	1	318
TELE 3704	TOTAL	19	450	5	9999999	9999999	1	319
TELE 3705		112	677483	6	80824	42342	16	320
TELE 3705	AMD	31	858474	6	24716	37324	15	321
TELE 3705	IBM	516	5282080	6	49118	89526	115	322
TELE 3705	IBMSOR	3	22482	3	999999	999999	2	323
TELE 3705	NCR	192	591625	6	31196	23665	22	324
TELE 3705	NCRCMP	1	3817	2	999999	999999	1	325
TELE 3705	TOTAL	855	7435963	6	42954	60454	170	326
TELE 3705T		1	1186	5	999999	999999	1	327
TELE 3705T	AMD	4	164	5	613	9999999	1	328
TELE 3705T	IBM	20	16597	6	196	233	15	329
TELE 3705T	NCR	14	42208	6	27423	999999	10	330
TELE 3705T	NCRCMP	1	498	2	29	29	1	331
TELE 3705T	TOTAL	40	60656	6	838	689	28	332
TELE 3725	IBM	887	19155858	6	15033	17088	235	333
TELE 3725	TOTAL	887	19155858	6	15033	17088	235	334
TELE 3725T	IBM	7	1441	6	81	48	6	335
TELE 3725T	TOTAL	7	1441	6	81	48	6	336
TELE 3791		43	75759	6	999999	999999	3	337
TELE 3791	CCU	4	3366	5	9999999	9999999	1	338
TELE 3791	IBM	392	1019706	6	1157488	509853	46	339
TELE 3791	LEE	6	5845	6	999999	999999	1	340
TELE 3791	TOTAL	445	1104677	6	1252843	552338	61	341
TAPE 3265	MEM	3	202	6	509	202	2	342
TAPE 3265	TOTAL	3	202	6	509	202	2	343
TAPE 3266	MEM	62	116071	6	1959	1488	11	344
TAPE 3266	TOTAL	62	116071	6	1959	1488	11	345
TAPE 3288	MEM	115	376843	6	2250	2243	6	346
TAPE 3288	TOTAL	115	376843	6	2250	2243	6	347
TAPE 3410	PAR	23	3036	6	129	138	7	348
TAPE 3410	TOTAL	23	3036	6	129	138	7	349
TAPE 34203	IBM	49	56198	6	1061	1080	21	350
TAPE 34203	PAR	10	2158	6	2240	719	4	351
TAPE 34203	STC	30	4037	6	579	288	17	352
TAPE 34203	STCCUS	2	117	5	413	999999	1	353

TAPE 34203	STCRAY	1	1	4	97	9999999	1	354
TAPE 34203	TOTAL	92	62513	6	986	905	43	355
TAPE 34204	IBM	74	87411	6	2947	1344	24	356
TAPE 34204	IBMDAT	1	99	5	888	999999	1	357
TAPE 34204	IBMSOR	2	1344	6	10400	9999999	1	358
TAPE 34204	STC	66	108000	6	1636	923	13	359
TAPE 34204	STCCUS	2	2199	5	511	274	1	360
TAPE 34204	STCNAS	24	36166	4	1109	1339	1	361
TAPE 34204	TOTAL	169	235223	6	2076	1083	41	362
TAPE 34205	IBM	86	270063	6	2108	2755	28	363
TAPE 34205	IBMSOR	5	541	6	1063	541	3	364
TAPE 34205	NAS	13	1289	4	125	107	1	365
TAPE 34205	STC	78	58360	6	639	555	37	366
TAPE 34205	STCCPY	2	2483	5	7803	999999	1	367
TAPE 34205	STCSYS	9	733	6	133	66	1	368
TAPE 34205	TOTAL	193	333472	6	1223	1469	71	369
TAPE 34206	IBM	1231	2882763	6	2267	2319	108	370
TAPE 34206	IBMCDC	10	13474	5	304	396	1	371
TAPE 34206	IBMCES	1	501	1	999999	999999	1	372
TAPE 34206	IBMDAT	9	4998	6	476	624	2	373
TAPE 34206	IBMSOR	52	259843	6	4974	3997	2	374
TAPE 34206	MEM	79	202389	6	2897	2594	11	375
TAPE 34206	STC	1594	3652139	6	2649	3278	97	376
TAPE 34206	STCQTX	18	14404	1	14404	14404	1	377
TAPE 34206	STCSPR	1	1830	4	976	228	1	378
TAPE 34206	TEL	57	82088	6	507	536	3	379
TAPE 34206	TOTAL	3052	7114433	6	2359	2631	223	380
TAPE 34207	CDC	4	5	5	999999	999999	1	381
TAPE 34207	IBM	174	431821	6	1063	1605	43	382
TAPE 34207	IBMCMP	47	71767	5	278	308	1	383
TAPE 34207	IBMSOR	2	236	4	96	118	1	384
TAPE 34207	IBMTLS	3	278	5	118	278	1	385
TAPE 34207	MEM	20	19997	6	1742	1428	10	386
TAPE 34207	NAS	4	2639	6	290	527	1	387
TAPE 34207	STC	121	122127	6	558	397	39	388
TAPE 34207	STCCMP	4	186	6	213	31	2	389
TAPE 34207	STCICS	2	364	6	1080	999999	1	390
TAPE 34207	STCSYS	17	14588	5	390	339	1	391
TAPE 34207	STCTEL	2	51	6	52	17	1	392
TAPE 34207	TOTAL	400	664065	6	661	752	99	393
TAPE 34208	IBM	1978	4873565	6	2142	1965	181	394
TAPE 34208	IBMCES	9	14444	1	999999	999999	1	395
TAPE 34208	IBMDAT	2	870	5	6444	9999999	1	396
TAPE 34208	IBMSOR	13	74231	6	3095	4948	2	397
TAPE 34208	IBMTLS	5	3817	5	527	545	1	398
TAPE 34208	MEM	510	1440047	6	3135	2956	41	399
TAPE 34208	MEMSOR	13	40385	5	846	1121	1	400
TAPE 34208	NAS	22	38378	6	3653	4797	3	401
TAPE 34208	STC	2168	6966909	6	2673	3089	119	402
TAPE 34208	STCCMP	32	60754	6	1118	1104	2	403
TAPE 34208	STCCUS	4	5587	5	797	558	1	404
TAPE 34208	STCICS	30	60886	6	5982	4059	1	405
TAPE 34208	STCRAY	14	8552	4	319	285	1	406
TAPE 34208	STCSPR	31	80877	6	3843	5391	1	407
TAPE 34208	STCSYS	22	46611	6	898	832	1	408
TAPE 34208	STCTEL	7	9171	6	609	1310	1	409
TAPE 34208	STCTIS	24	76587	6	1777	1781	1	410
TAPE 34208	STCUNI	14	64127	5	1817	1603	1	411
TAPE 34208	TOTAL	4898	13865808	6	2439	2494	340	412
TAPE 3480	IBM	10814	1017674	6	312	341	350	413
TAPE 3480	IBMCES	4	423	1	999999	999999	1	414
TAPE 3480	IBMDAT	16	166	5	23	41	1	415
TAPE 3480	IBMSOR	72	7258	1	806	806	2	416
TAPE 3480	TOTAL	10906	1025524	6	306	342	354	417
TAPE 4530	STC	29	30054	6	990	1155	13	418
TAPE 4530	TOTAL	29	30054	6	990	1155	13	419
TAPE 4554	STC	134	155092	6	1770	866	27	420
TAPE 4554	TOTAL	134	155092	6	1770	866	27	421
TAPE 4670	STC	2363	6511431	6	4737	4543	110	422
TAPE 4670	STCCMP	4	672	2	179	224	1	423
TAPE 4670	TOTAL	2367	6512103	6	4733	4524	110	424

TAPE	80205	TEL	1	75	5	189	999999	1	425
TAPE	80205	TOTAL	1	75	5	189	9999999	1	426
TAPE	80206	TEL	34	64305	6	1395	3215	4	427
TAPE	80206	TOTAL	34	64305	6	1395	3215	4	428
MED	33301		0	222435	6	5909	11121	40	429
MED	333011		0	655995	6	5151	4753	66	430
MED	3340		0	5207	6	1173	1301	6	431
MED	3344		0	2265	5	999999	999999	1	432
MED	3420		0	31104472	6	1483	1468	612	433
MED	3480		0	1045757	6	610	732	355	434

System	Mean Time to Restart	Mean # of Instr. to Restart	% Hw	% Sw	% Unknown
B5500	14.7	2.6×10^{10}	39.3	8.1	52.6
Chi/05 (Univac 1108)	17	6.7×10^{10}	45	55	-
Dual 370/165	8.86	2.8×10^{11}	65	32	3
SLAC 2-370/168 1-360/91	20.2	2.3×10^{11}	73.3	21.6	5.1
PDP-10	10	4.3×10^{10}	-	-	-
Univac-large	-	-	51	42	7
Univac-Med.	-	-	57	41	2
Univac-Small	-	-	88	9	3

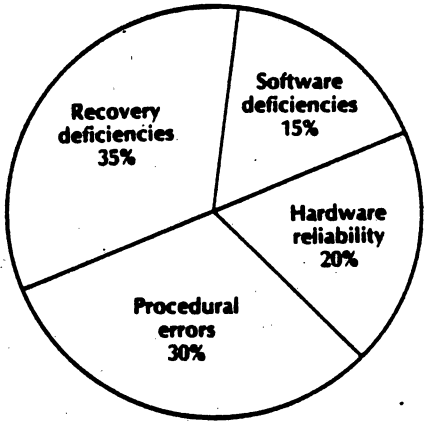


Figure -1. System outage allocation.

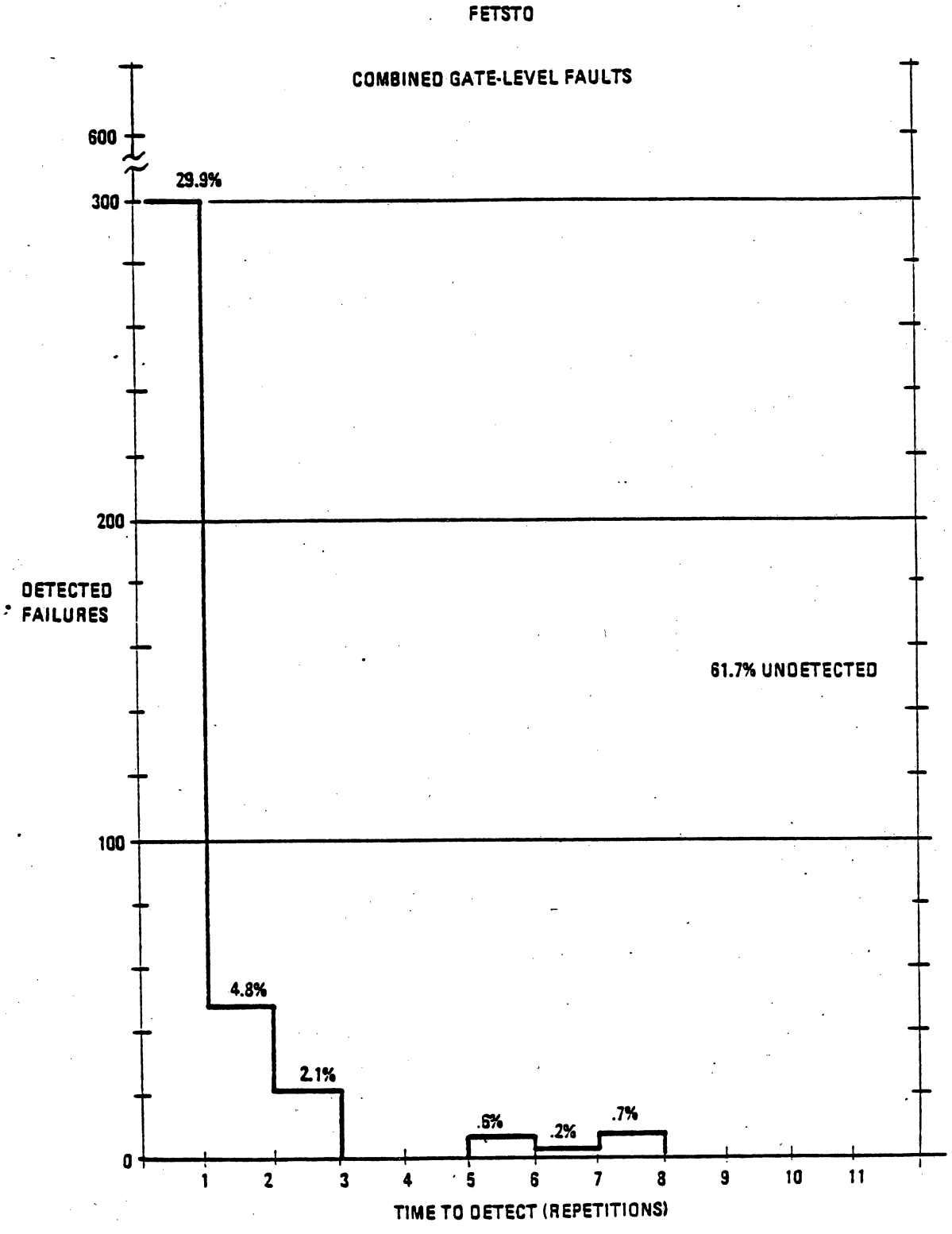

FETSTO
COMBINED GATE-LEVEL FAULTS
600
300
200
100
0
29.9%
61.7% UNDETECTED
4.8%
2.1%
.6%
.2%
.7%
DETECTED FAILURES
1
2
3
4
5
6
7
8
9
10
11
TIME TO DETECT (REPETITIONS)

FIGURE 2a

FETSTO

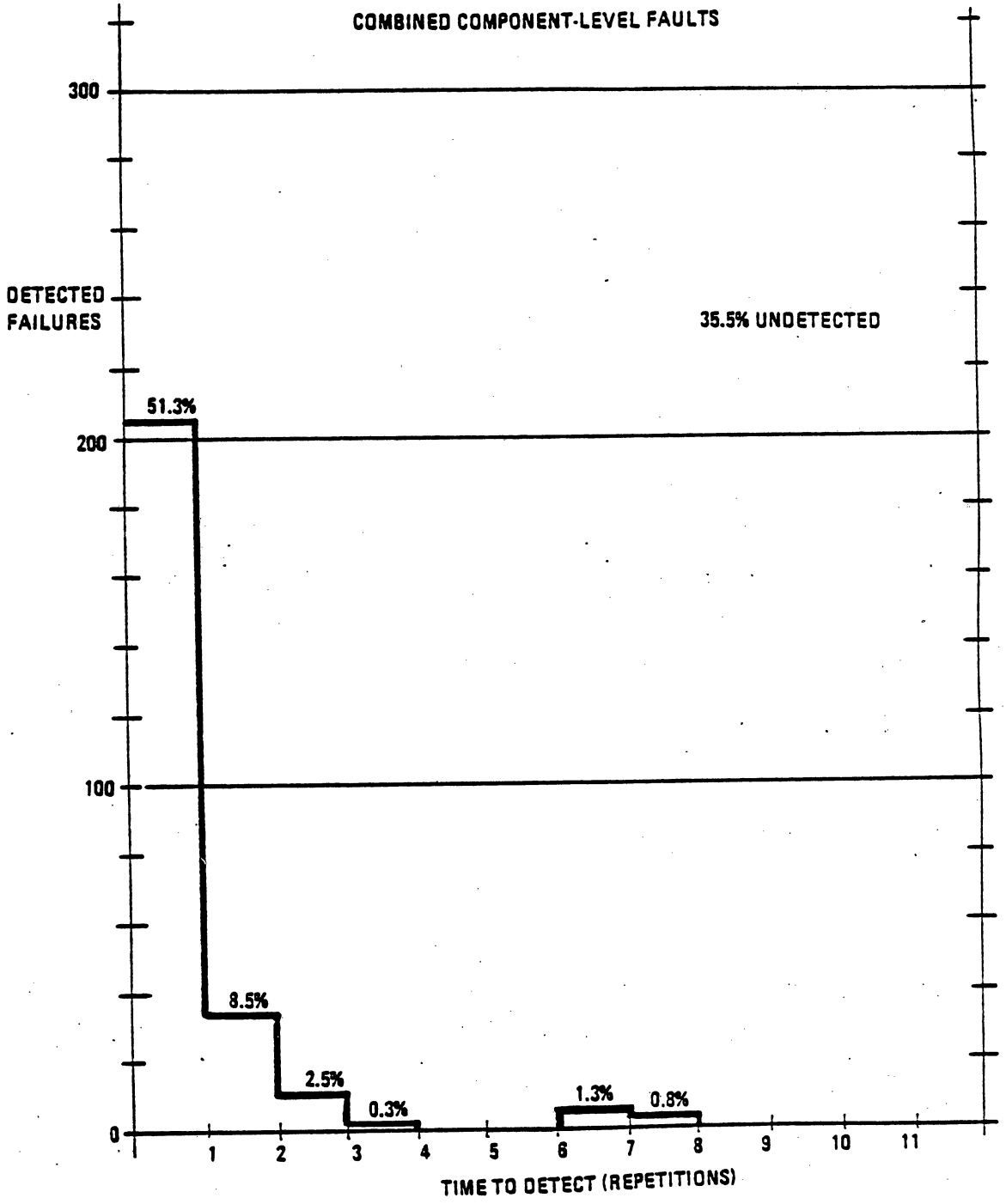


FIGURE 2f

WHY DO COMPUTERS STOP?

Jim Gray

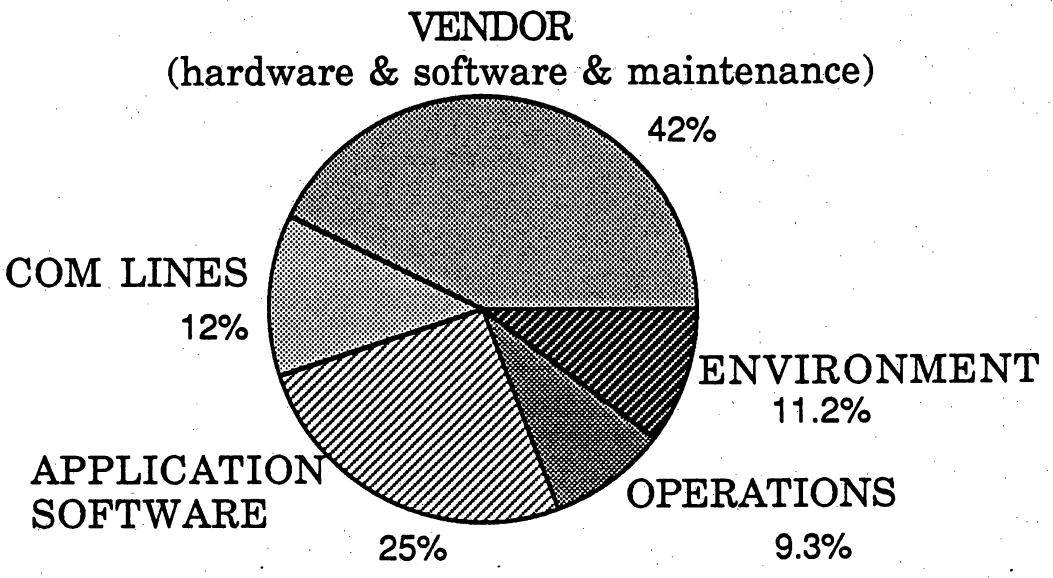
Tandem

Sept 1987

ANOTHER CASE STUDY

JAPANESE COMPUTER USERS

"Survey on Computer Security", Japan Info Dev Corp, March 1986. (trans: Eiichi Watanabe).



VENDOR (HARDWARE & SOFTWARE)	5 Months
APPLICATION SOFTWARE	9 Months
COMM LINES	1.5 Years
OPERATIONS	2 Years
ENVIRONMENT	2 Years
	10 Weeks

1,383 INSTITUTIONS REPORTED (6/84 - 7/85)

7,517 OUTAGES

MTBF ~ 10 WEEKS

AVG DURATION ~ 90 MINUTES

DOES DISC DUPLEXING WORK?

1987 Numbers: 50,000hr MTBF (6 years)
5hr MTTR

=> ~ 65,000 year MTBF

OBSERVED IN LAST 24 MONTHS:
35 double fails on ~46,400 pair/years
~ 1300 years

CONCLUSION:

IT WORKS WELL (200x better than no duplex).

FAILURES NOT INDEPENDENT
NOT UNIFORM
INVOLVE CONTROLLERS...
(50x worse than theory)

1985 STATISTICAL BASE

2400 SYSTEMS ~ 10,000 PROCESSORS

~ 40,000 DISCS

9/84 - 6/85 => 1,000 SYSTEM YEARS

=> 5,000 CPU YEARS

=> 20,000 DISC YEARS

166 REPORTED SYSTEM FAILURES

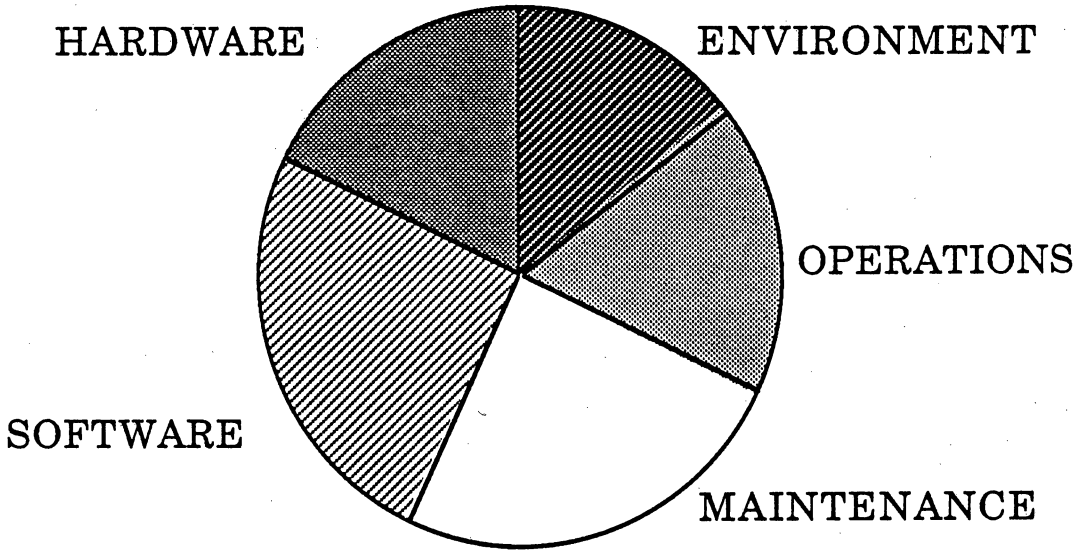
SUBTRACTED INFANT MORTALITY:

	CUSTOMERS
* A NEW BOX:	6
* A NEW PIECE OF SOFTWARE:	2
* SIMPLEX DISCS	2

(2% OF CUSTOMERS HAD 30% OF DOWNS)

107 SYSTEM FAILURES REMAIN

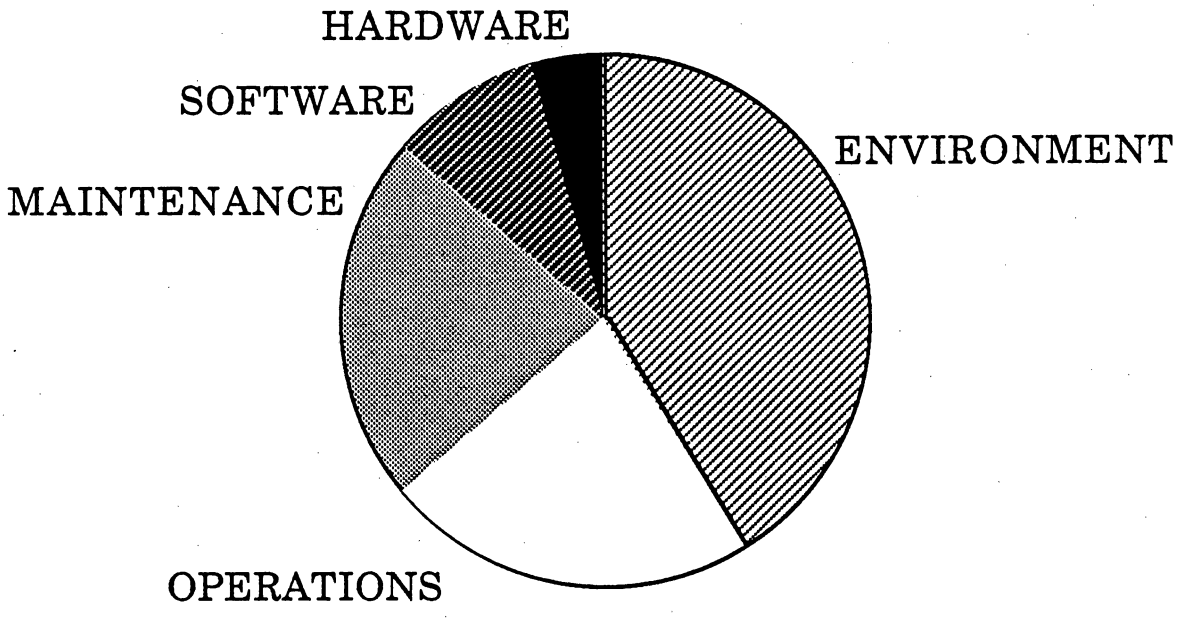
TANDEM EWR DATA



HARDWARE	73 Years
SOFTWARE	50 Years
OPERATIONS	65 Years
MAINTENANCE	50 Years
ENVIRONMENT	87 Years
SYSTEM	11 Years

REMEMBER SYSTEMATIC UNDERREPORTING

BEST GUESS BASED ON FOUR LARGE CUSTOMERS



HARDWARE	~~73 Years~~	50 Years
SOFTWARE	~~50 Years~~	25 Years
OPERATIONS	~~65 Years~~	20 Years
MAINTENANCE	~~50 Years~~	20 Years
ENVIRONMENT	~~87 Years~~	10 Years
SYSTEM	~~11 Years~~	4 Years

WHAT ARE THE CHANCES OF TOLERATING A FAULT

PROCESSOR & DISC RATED AT ~ 10Khr MTBF

	COMPUTED SINGLE FAILURES	OBSERVED DOUBLE FAILS	RATIO
=>	10K PROCESSOR FAILS,	14 DOUBLE	~ 1000:1
=>	40K DISC FAILS,	26 DOUBLE	~1000:1

SOFTWARE FAULTS ARE SOFT:

ADAMS: MOST SOFTWARE FAULTS ARE BENIGN

GRAY: PROCESS PAIR EXPERIMENT SHOWED BACKUP TOLERATED 140:1

Mourad's SLAC STUDY: MVS-XA FRR >5:1

Adams: "Optimizing Preventative Service of Software Products", IBM J R&D,28.1,1984

Gray: "Why Do Computers Stop", Tandem TR85.7, 1985

Mourad: "The Reliability of the IBM/XA Operating System", 15 ISFTCS, 1985.

1987 STATISTICAL BASE

1300 CUSTOMERS

6000 SYSTEMS ~ 16,000 PROCESSORS

~ 97,000 DISCS

6/85 - 6/87 => 12,000 SYSTEM YEARS

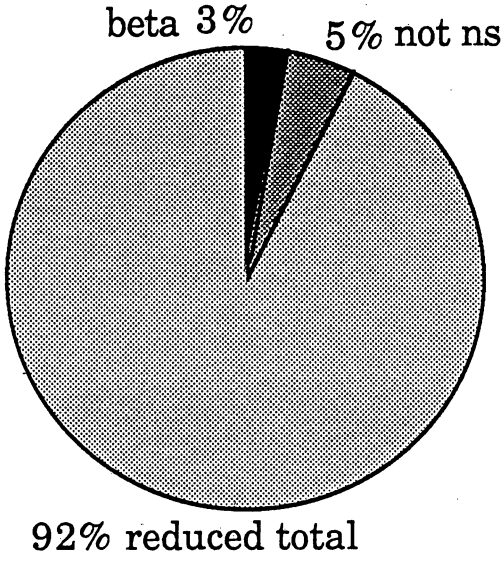
=> 32,000 CPU YEARS

=> 97,000 DISC YEARS
48,000 PAIR YEARS

490 REPORTED SYSTEM FAILURES

205 CUSTOMERS REPORTED OUTAGES

MOST REPORTS WERE FOR PRODUCTION SYSTEMS



SUBTRACTED:

	REPORTS
* BETA TESTS	16
* SIMPLEX DISCS	23

* ONE CUSTOMER WITH A 2 DAY MTBF!

451 "VALID" OUTAGES REMAIN

SUMMARY OF STATISTICS

5/6 CUSTOMERS REPORTED NO OUTAGE IN 2 YEARS

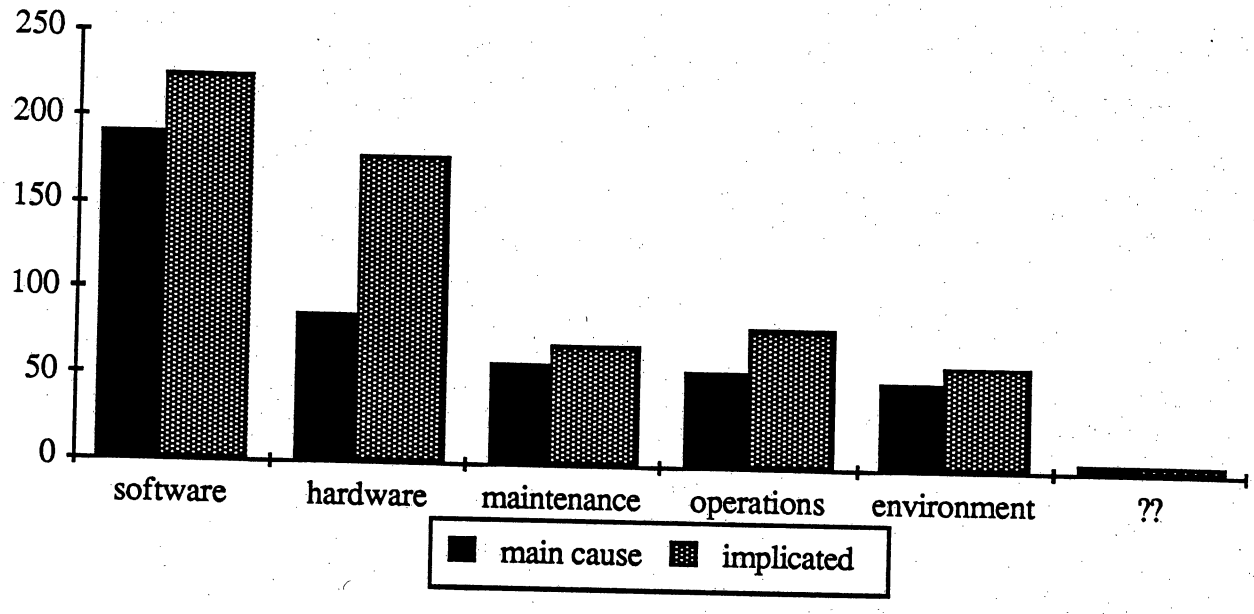
COMPONENT	MTBF
HARDWARE	140 Years
SOFTWARE	63 Years
OPERATIONS	211 Years
MAINTENANCE	200 Years
ENVIRONMENT	235 Years
SYSTEM	27 Years

REMEMBER, SYSTEMATIC UNDER-REPORTING OF
OPERATIONS,
MAINTENANCE, &
ENVIRONMENT.

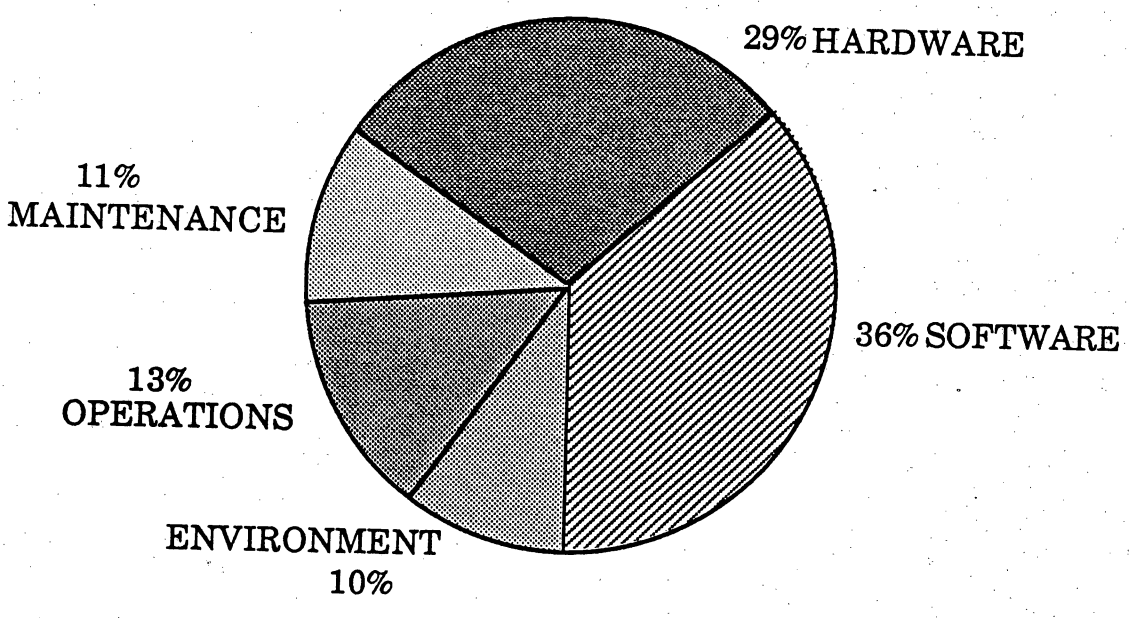
CPU PAIR:	877 Years
DISC PAIR:	1325 Years

Note: introducing a new processor and a new disc drive skewed these statistics

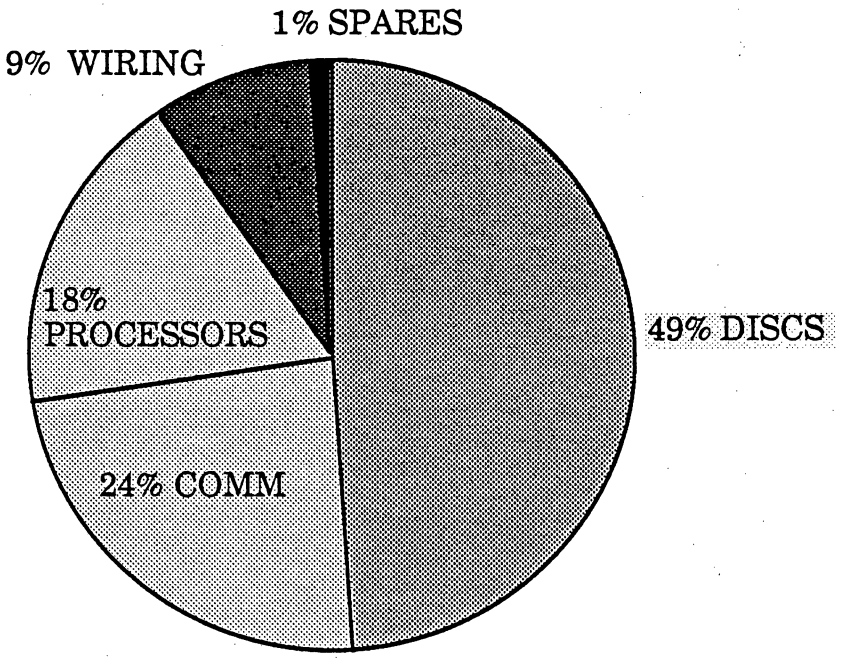
CAUSES OF OUTAGES



HEREAFTER,
ALL COUNTS BASED ON **IMPLICATED** CAUSES



HARDWARE CAUSES OF OUTAGES

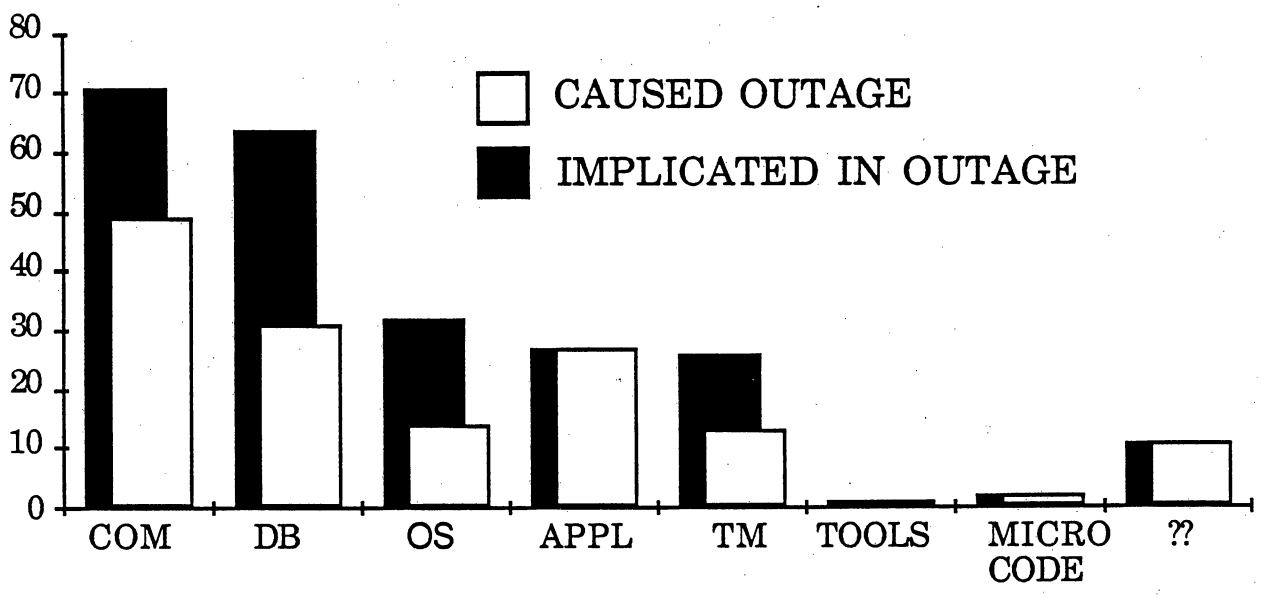


COMMUNICATIONS TYPICALLY NOT DUPLEXED
VIRTUALLY ALL COMM FAILURES
WERE SINGLE FAILURES

THERE ARE 16K PROCESSORS
48K DISCS

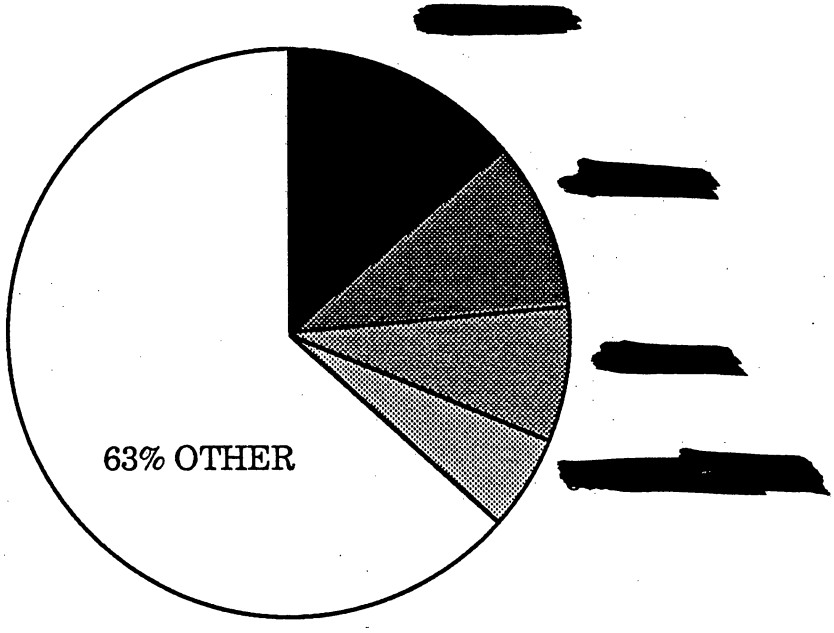
3X AS MANY DISCS AND 3X AS MANY FAILURES

SOFTWARE FAULTS BY COMPONENT

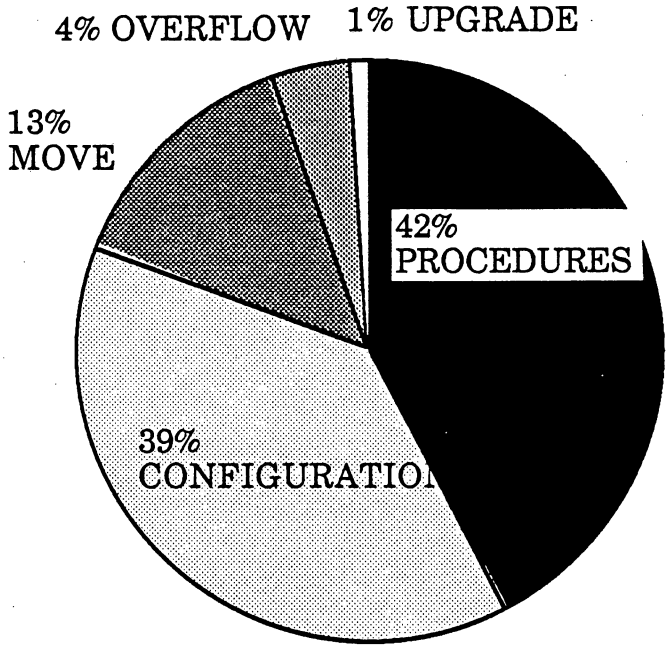


DURING THIS PERIOD,
A COMPLETE REWRITE OF THE DATA BASE &
60% REWRITE OF TRANSACTION MANAGEMENT &
A VERY COMPLEX COMMUNICATIONS PRODUCT
WERE INTRODUCED

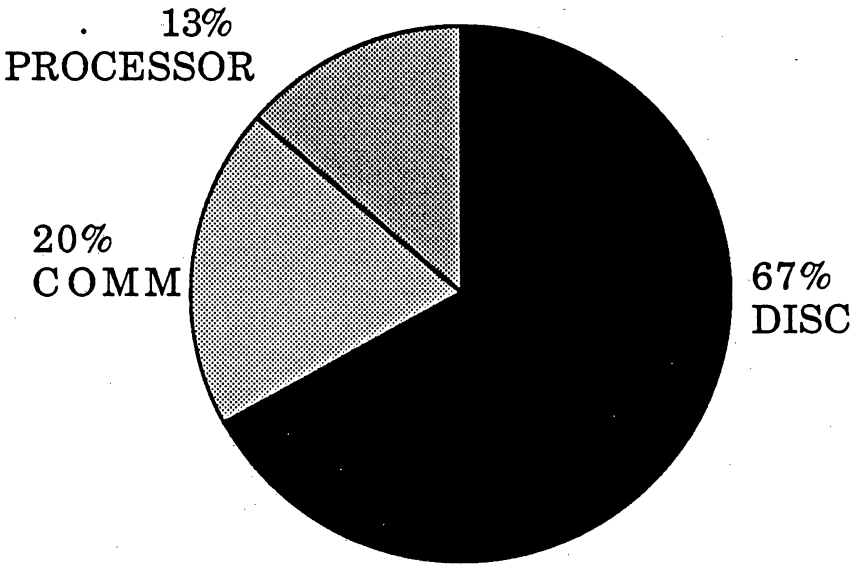
COMMON BUGS: 36% OF THE CASES!



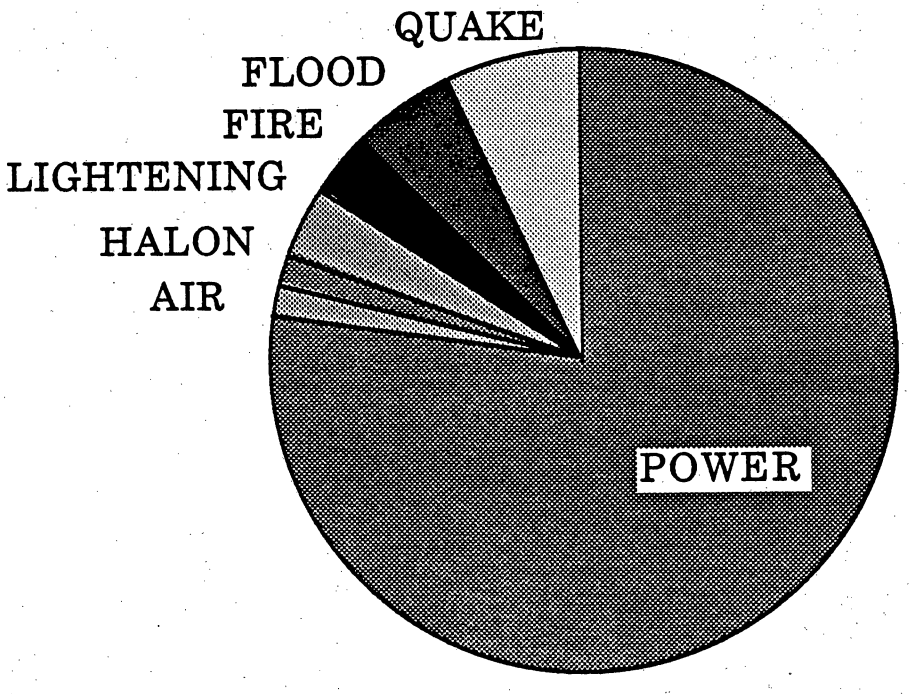
OPERATIONS CAUSES OF OUTAGES



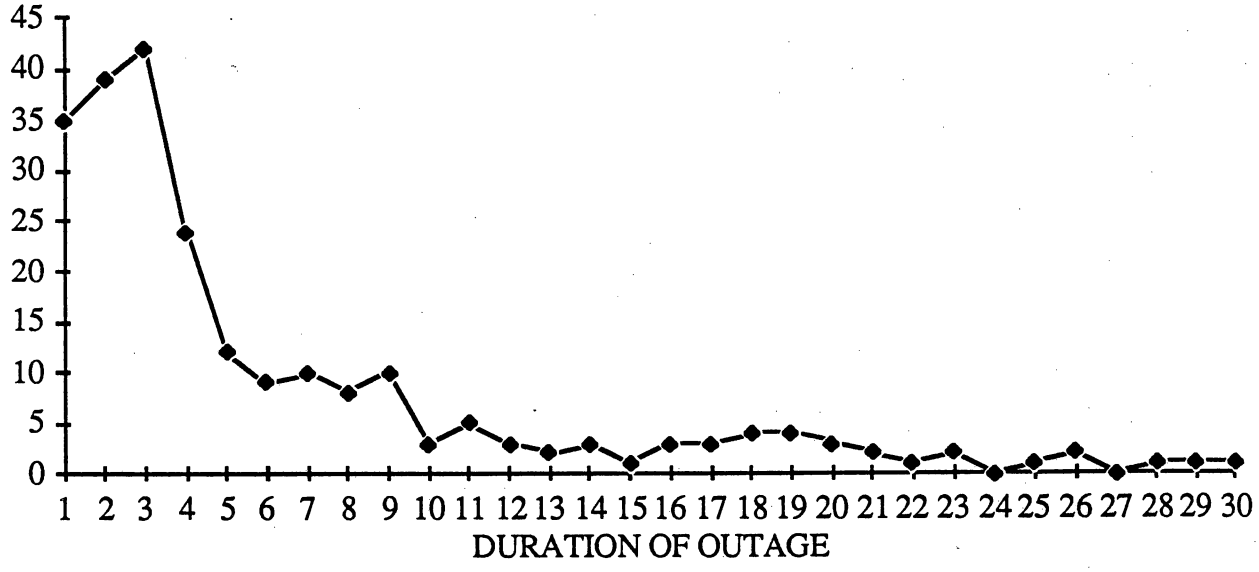
MAINTENANCE CAUSES OF OUTAGES



ENVIRONMENT CAUSES OF OUTAGES



DURATION OF OUTAGES



48% OF OUTAGES REPORTED DURATION

3 HOURS IS THE MODE & MEDIAN

6.5 HOURS IS THE AVERAGE

NOT SHOWN ARE:

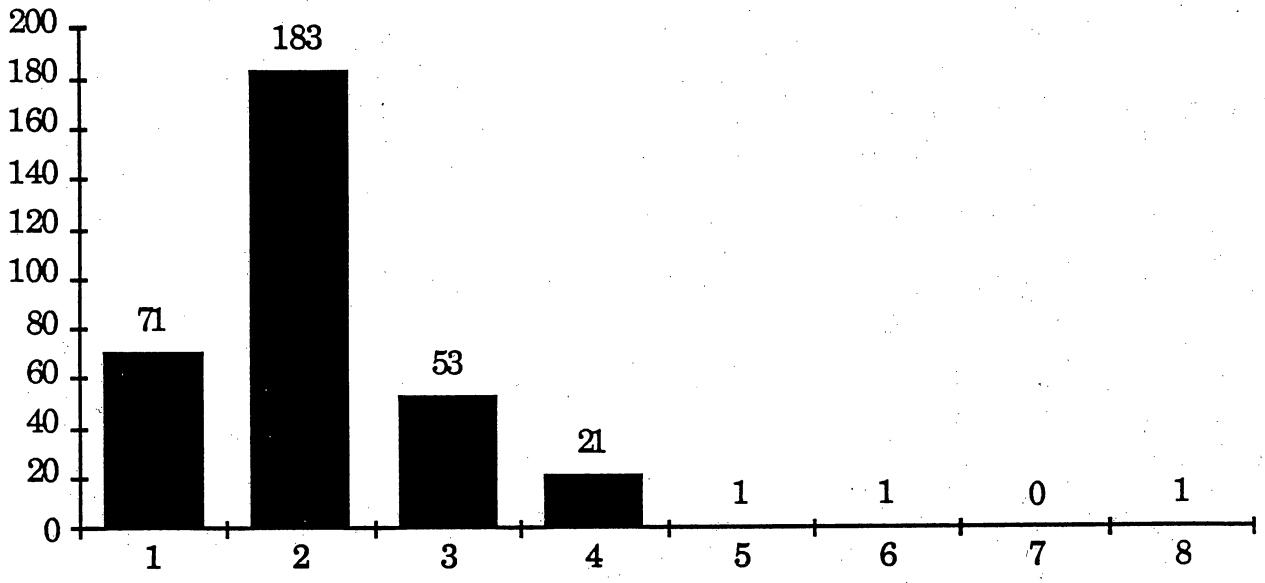
1 OUTAGE OF 48 HOURS

1 OUTAGE OF 57 HOURS

2 OUTAGES OF 73 HOURS (Tornado)

1 OUTAGE OF 85 HOURS (more Tornado)

LENGTH OF FAULT CHAINS



FAULT CHAINS = 1 ARE COMMON BECAUSE

DISASTER (power, fire, flood,...)

OPERATIONS DISASTERS

MAINTENANCE DISASTERS

FAULT CHAINS >2 ARE COMMON BECAUSE:

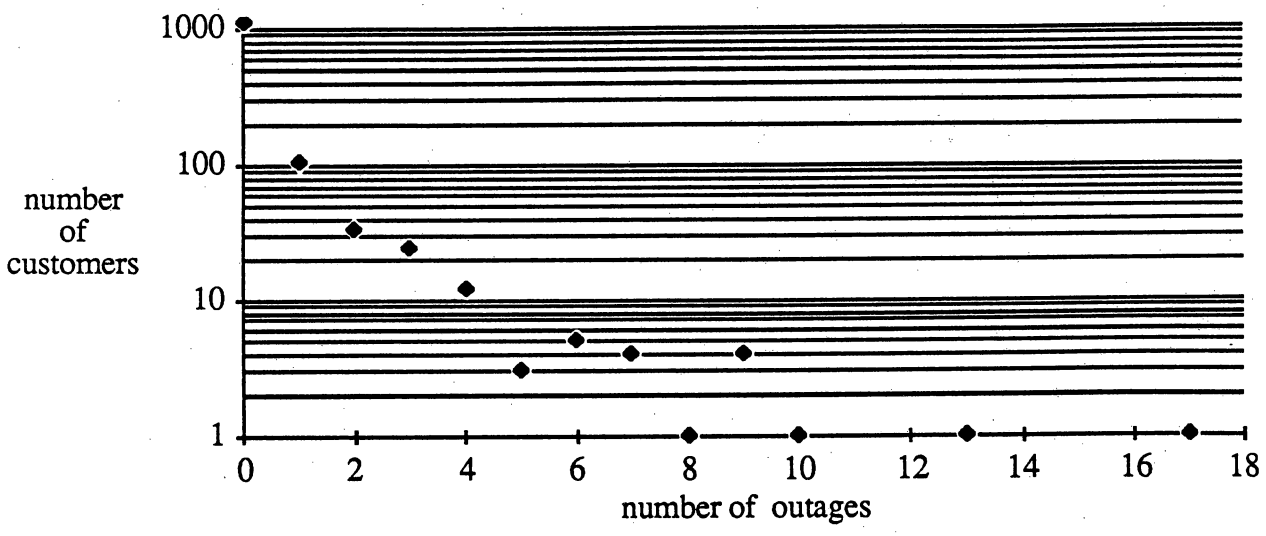
HUMAN ERROR RATE IS HIGH

RECOVERY PROCEDURES ARE COMPLEX

RECOVERY SOFTWARE IS LESS WELL TESTED

LATENT FAULTS ARE COMMON (50 REPORTED)

NUMBER OF CUSTOMERS REPORTING N OUTAGES



MOST CUSTOMERS HAD NO COMPLAINT IN 2 YEARS

BIG CUSTOMERS COMPLAIN THE MOST

BUT DISPROPORTIONATLY LESS THAN SMALL ONES

SOME CUSTOMERS HAVE LOTS OF PROBLEMS

THIS SEEMS TO BE INDEPENDENT OF SIZE

MOST CUSTOMERS HAVE NO OUTAGES

ALL BIG CUSTOMERS HAVE SOME OUTAGES

E.G. CUSTOMER WITH 140 CPUS & 20 SYSTEMS SHOULD EXPECT ~ 1 OUTAGE / YEAR.

Table 1. Power outages at Bell Canada equipment locations

Summary of BNR study data	
Number of equipment locations	350
Aggregate monitoring time	8376 months
Number of outages recorded	1420
Aggregate downtime	3600 hours
Average number of outages per month per location	0 17
Average outage duration	2 54 hours
Breakdown of outages by duration	
Outage duration (hours)	**Number of outages**
0 – 0 5	476
0 5 – 1	222
1 – 2	225
2 – 4	248
4 – 8	167
8 – 24	69
>24	13

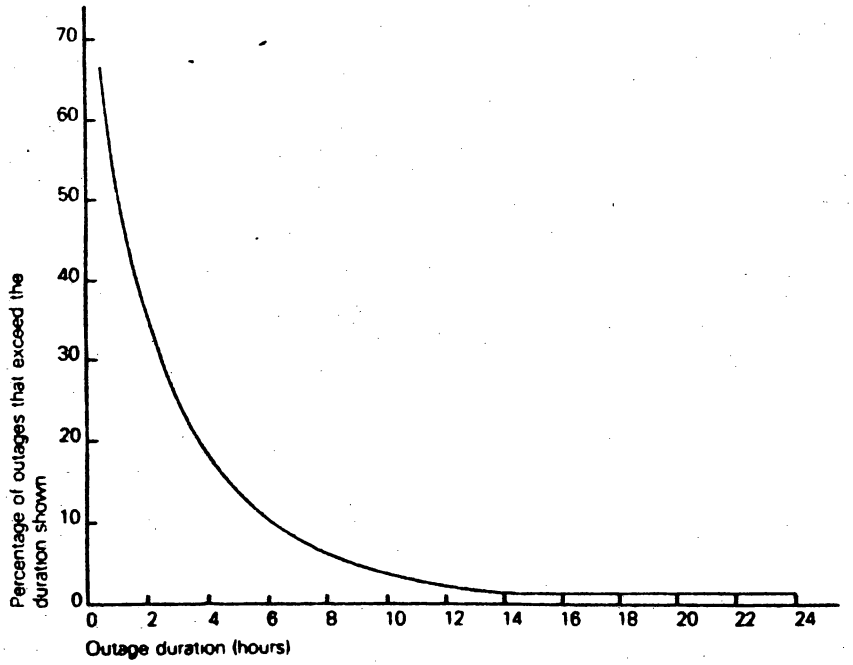


Figure 1. This figure of the cumulative distribution of outage durations is based on outage records that cover 350 Bell Canada locations for a total combined interval of 3376 months. The graph represents the percentage of outages t eded the durations marked on the l axis. For example, about 24 percent of the outages exceed three hours. This means that if batteries that provided three hours of reserve power had been available at all locations, an average 24 percent of outages would have required engine-alternator power to maintain operation.

Summary of BNR study findings

Sags less than 115 Vrms	
Average number of sags recorded per month per location	10 4
Average sag duration	27
Lowest voltage recorded during study	
Surges greater than 125 Vrms	
Average number of surges recorded per month per location	
Highest voltage recorded during study	
Impulses greater than 142 Vp	
Average number of impulses recorded per month per location	1
Average impulse duration	0 3 m
Highest voltage recorded during study	228 Vp

Table 3. Typical input parameters for ac-powered computer systems

Parameter	**Nominal value**	**Value range**
Input voltage	120 V	104 – 127 V indefinitely
		96 – 138 V for 0 5 s
		84 – 144 V for 0 05 s
		60 V for 8 ms
		0 V for 4 ms
Frequency	60 Hz	57 – 63 Hz
Harmonic distortion	5 percent	
Lightning surges (resilience to)	1500 V (impulse or ring wave)	500 – 2500 V, depending on power supply protection
Power factor		−0 8 to +0 8
Inrush current	10 times the steady state current	

Source: BNR: NorthernBell "Telesys" 1984 Vol 1

Table 2–6. Die-related failure modes: SSI, MSI, LSI standard TTL.

Failure Classification	*SSI STD TTL*		*MSI STD TTL*		*LSI STD TTL*	
	No. Devices	*%*	*No. Devices*	*%*	*No. Devices*	*%*
Surface defects	51	20%	10	11%	5	8%
Contamination	29	11	5	6	2	3
Foreign material/ stray particles	7	3	4	5	1	2
Inversion/channeling	11	4	1	1	2	3
Surface leakage	4	2				
Bulk defects	24	9	5	6	0	0
Crystal imperfections	2	1	3	3		
Cracked, chipped die	22	8	2	2		
Oxide defects	27	10	10	11	22	33
Gate oxide pinholes						
Field oxide pinholes	8	3	6	7	12	18
Oxide fault	19	7	3	3	3	4
Oxide short/ breakdown					5	8
Passivation defect			1	0	2	3
Diffusion defects	19	7	13	15	0	0
Diffusion anomaly	4	2	9	10		
Diffusion spike/ piped junction	3	1	2	2		
Isolation defect	1	0				
Mask fault	11	4	2	2		
Metalization defects	136	52	38	43	39	59
Open at oxide step						
Open at contact window	85	33	4	5		
Open/not specified	13	5	10	11	11	17
Short/interlayer metal	8	3	7	8	9	13
Short/not specified	22	8	15	17	17	26
Pitted/corroded	5	2				
Smeared/scratched	3	1	2	2	2	3
Electromigration						
Input/output circuit defects	5	2	12	14	0	0
Excessive input leakage	1	0	6	7		
Input circuit short	2	1	4	5		
Excessive output leakage			1	1		
Output circuit short	2	1	1	1		
Total	262		88		66	

Table 2–7. Die-related defect summary: SSI, MSI, LSI standard TTL.

General Defect Classification	*No. Malfunctions*	*Relative Percent*
Surface	66	16%
Bulk	29	7
Oxide	59	14
iffusion	32	8
Metalization	213	51
Input/output circuit	17	4

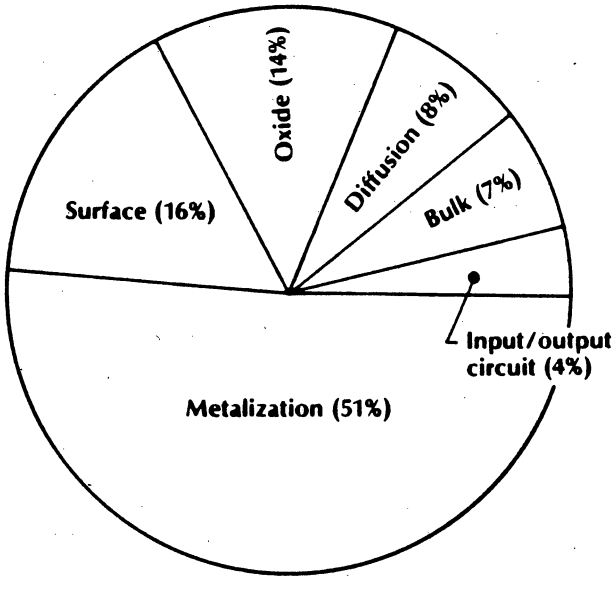


Table 2–8. Screening test summary.

Screening Tests	*Subtrate Bonding Defects*	*Subtrate Thin Film Defects*	*Bulk Silicon Defects*	*Silicon Surface Defects*	*Contamination or Corrosion*	*Wire Bonding Defects*	*Die Metalization Defects*	*Electrical Stability*	*Resistor and Chip Defects*	*Hermetic Seal Defects*	*Package Defects*	*External Lead Defects*	*Cracked Die or Substrates*
Wafer probe		x	x				x	x	x				
fer inspection				x	x		x						x
rrecap inspection	x	x		x	x	x	x						x
Stabilization bake			x	x	x	x	x	x					
Thermal cycling	x	x		x		x	x		x	x	x		x
Thermal shock	x	x		x		x	x		x	x	x		x
Hermeticity										x	x		
Centrifuge	x				x	x					x		
Mechanical shock	x				x	x					x		x
Vibration	x				x	x					x		
Burn-in		x	x	x	x	x	x	x					
Radiographic	x				x	x				x			x
External visual										x	x	x	
Scanning Electron Microscope		x		x	x		x						x

IFA Results

	Fault Types	Number	Percentage
1.	Line Stuck At Faults	132	28%
2.	Transistor Stuck At Faults	70	15%
3.	Floating Line Faults	101	21%
4.	Bridging Faults	144	30%
5.	Miscellaneous Faults	29	6%
	Total	476	100%

Some Observations

- Nonclassical faults are likely
- Not all faults are equally likely
- Only 28% of the observed faults are explicitly Line Stuck At 0/1 Faults.
- At best only 64% (28% + 15% + 21%) of the faults can be modeled by the stuck at fault model.
- Bridging Faults constitute a large percentage (30%) of the faults.

FACTS WE HAVE LEARNED ABOUT TRANSIENTS

- Transients 20-50 times more frequent than hard failures
- Transient causes non-classic errors
  Transients have different extents
- Transients follow a decreasing failure rate
  ⟶ clustering
- Assuming exponential reliability function for transients when actual is Weibull can lead to incorrect conclusions.
- Software/Hardware ratio about 2:1
- Recovery mechanisms can prevent 80% of system crashes

Transient - due to temporary environment conditions

- no physical damage

Typical system	MTBF	MTTC
	1 to 4k Hrs.	20 to 100 Hrs.

Transients 20 times more prevalent than hard failures.

C.mmp

PROBLEMS OBSERVED (Hardware)

- Parity errors most dominant failure mode
- False "NXM's" (Non-Existing Memory)
- No response
- Clock nonmontonic
- Register specified not always selected
- Stack operations may push/pop too many (too few) operands on stack (JSR, RTS, RTI)
- Loss of interrupts, change interrupt levels
- Deadlocked memory ports due to incomplete bus cycle
- DMA overrun due to memory contention
- I/O devices do not return to an initial state when issued an illegal command

	No. Ins.	No. Det.	%	Avg. Lat. (in μs)	Std. Dev. (in μs)	Tolerated w/perm. changes
Fault Duration						
1 cycle	493	202	41	13,000	85,000	43
2 cycles	484	298	61	12,000	70,000	56
4 cycles	460	313	68	14,000	91,000	52
Bus Type						
Inst	1053	724	69	4100	42,000	122
Data	384	89	23	82,000	200,000	29
Line Faulted						
D0	131	79	60	4300	23,000	19
D7	131	78	60	1200	9000	9
D8	131	63	48	1600	10,000	11
D15	130	81	62	210	550	17
A1	131	72	55	450	960	16
A4	131	67	51	24,000	110,000	15
A8	129	76	59	1600	10,000	13
A12	131	94	72	81,000	210,000	58
LDS	131	97	73	98	520	8
UDS	130	92	71	51	200	8
DTACK	131	14	11	43,000	100,000	5
Total/Avg.	1437	831	58	13,000	82,000	151

	No. Ins.	No. Det.	%	Avg. Lat. (in μs)	Std. Dev. (in μs)	Tolerated w/perm. changes
Fault Duration						
1 cycle	517	343	66	5400	61,000	17
2 cycles	462	402	87	5200	60,000	27
4 cycles	475	442	93	1400	27,000	35
Bus Type						
Inst	1124	1097	98	38	36	62
Data	330	90	27	51,000	180,000	17
Line Faulted						
D0	132	110	83	74	210	4
D7	132	111	84	79	230	4
D8	132	106	80	91	480	5
D15	132	108	82	65	190	4
A1	132	112	85	110	410	9
A4	132	103	78	65	200	5
A8	132	104	79	160	1000	4
A12	132	115	87	39,000	160,000	39
LDS	132	108	82	41	190	3
UDS	134	105	78	50	200	2
DTACK	132	105	80	79	190	0
Total/Avg.	1454	1187	82	3800	51,000	79

Effect of Fault	Number of faults
Detected by MC68000	680
Detected by MC68000 (tolerated w/perm. changes)	117
No voted data error	133
No voted data error (tolerated w/perm. changes)	4
Voted data error	447
Voted data error (tolerated w/perm. changes)	30
Unrecoverable errors (unmaskable errors in data or inability to completely execute benchmarks)	26
Total	1437

Exp. 1 Det. By	Exp. 2 Det. By	No. Det.	Exp. 1 Lat.	Exp. 2 Lat.
MC68000	MC68000 (same latency)	103	19μs	19μs
MC68000	MC68000 (lesser latency)	117	7.8ms	5.0ms
MC68000	MC68000 (greater latency)	92	170μs	210μs
MC68000	SIS	122	23.0ms	9.5ms
MC68000	NONE	7	51.0ms	-
NONE	MC68000	38	-	29μs
NONE	SIS	159	-	63μs
NONE	NONE	152	-	-

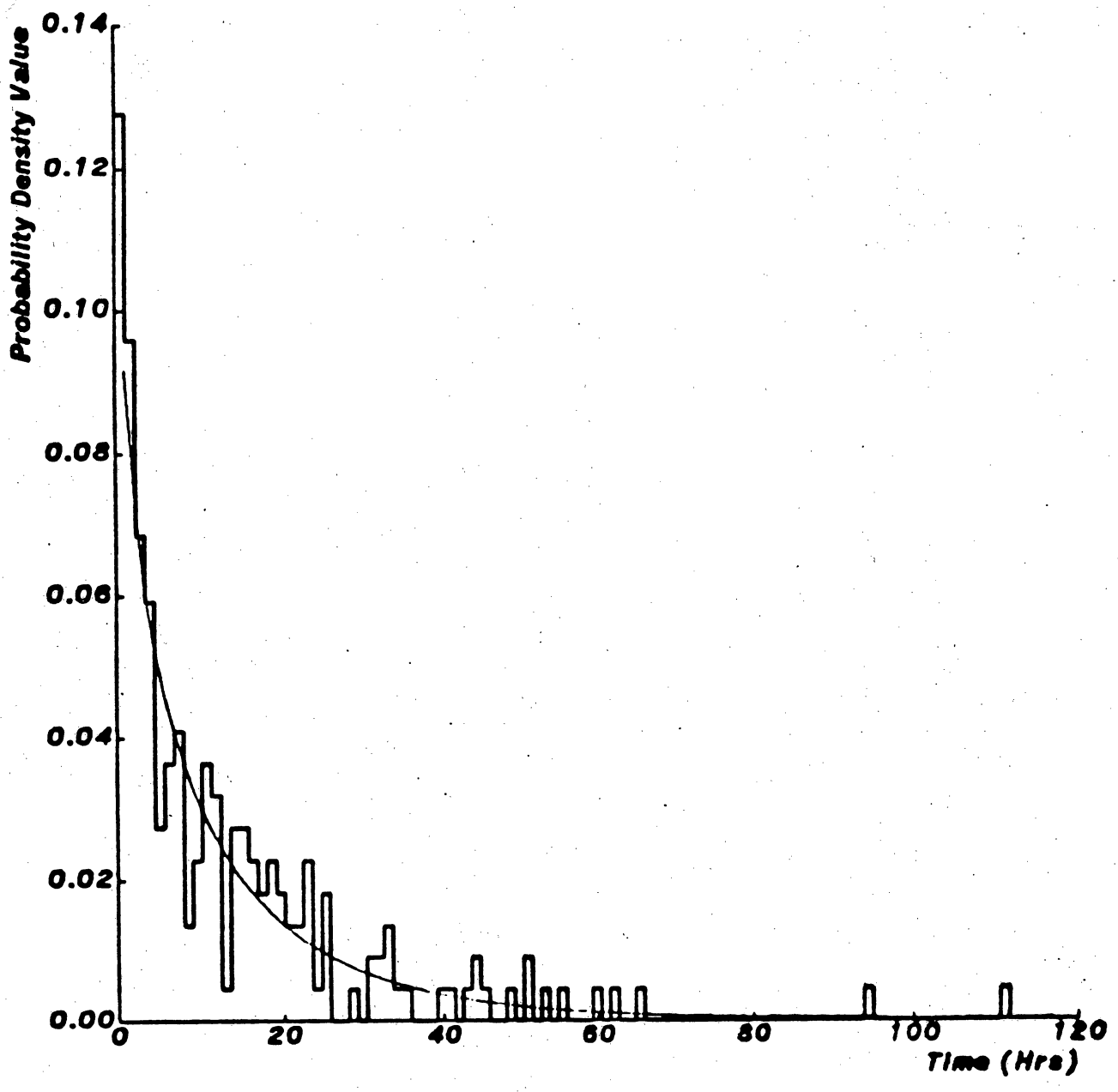


Figure 3-1: Distribution of TOPSC System Reloads

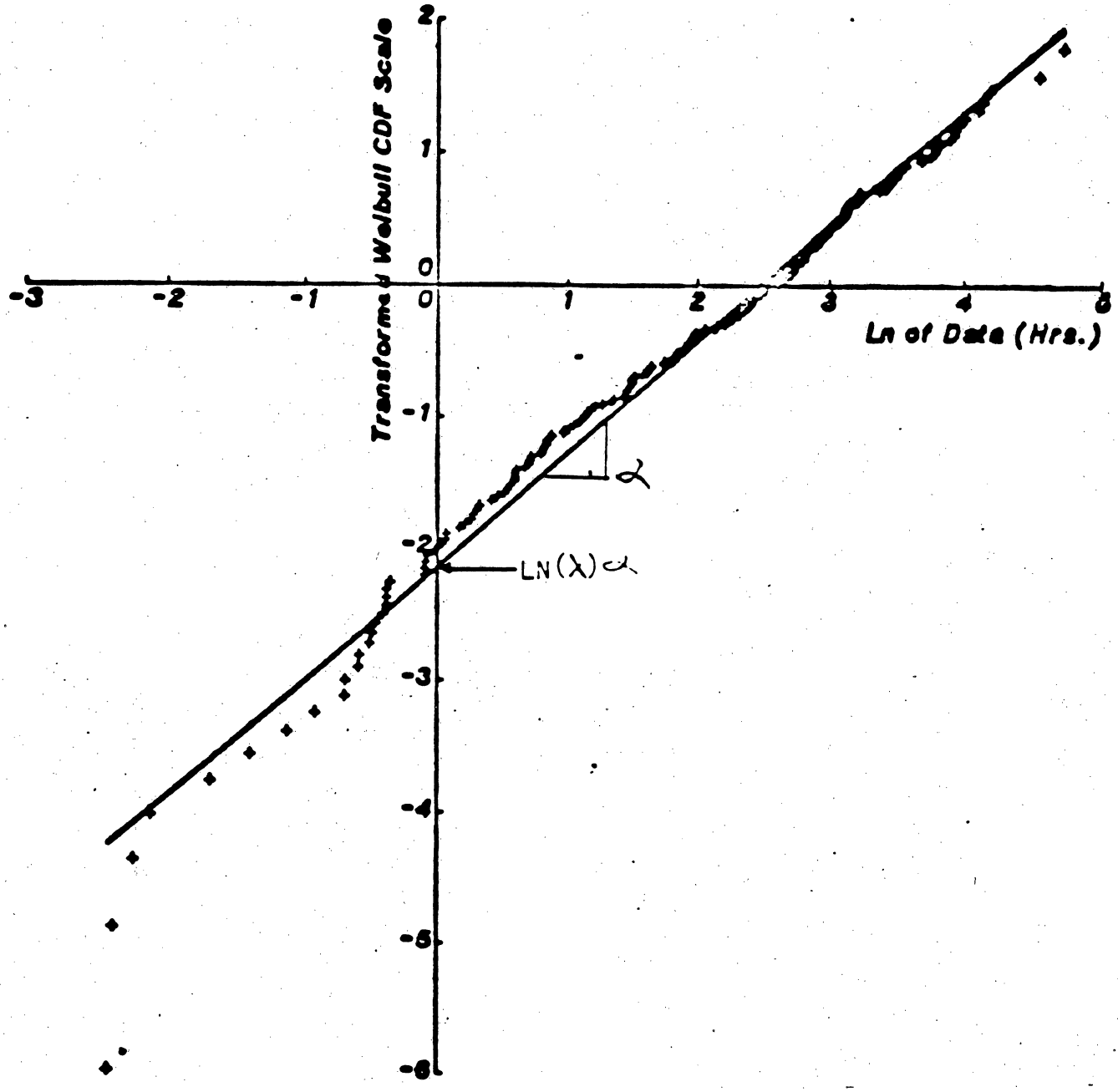


Figure 3-2: Weibull Plot of TOPSC System Records

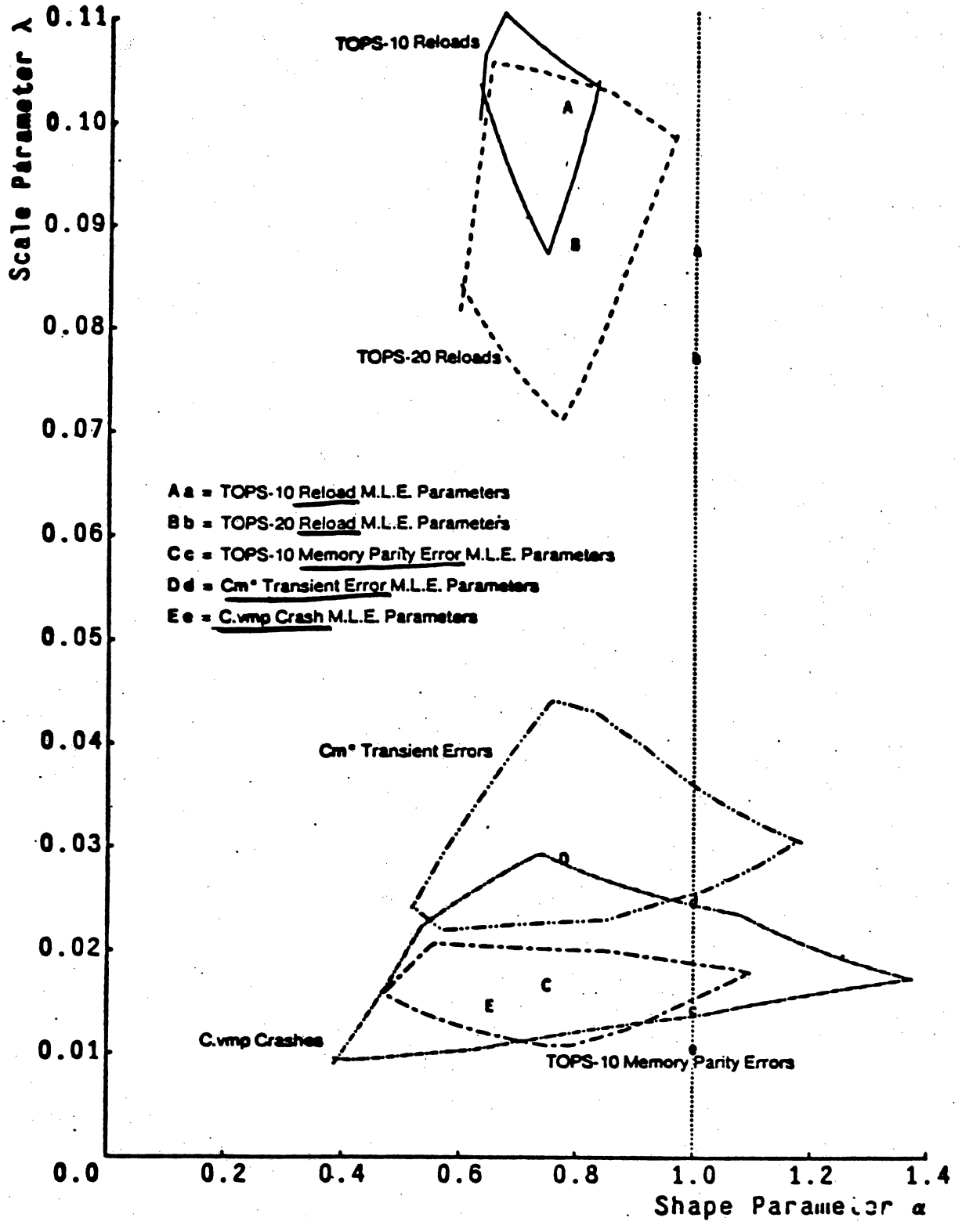


Figure 2-1: 90% Consonance Sets for Weibull Parameters

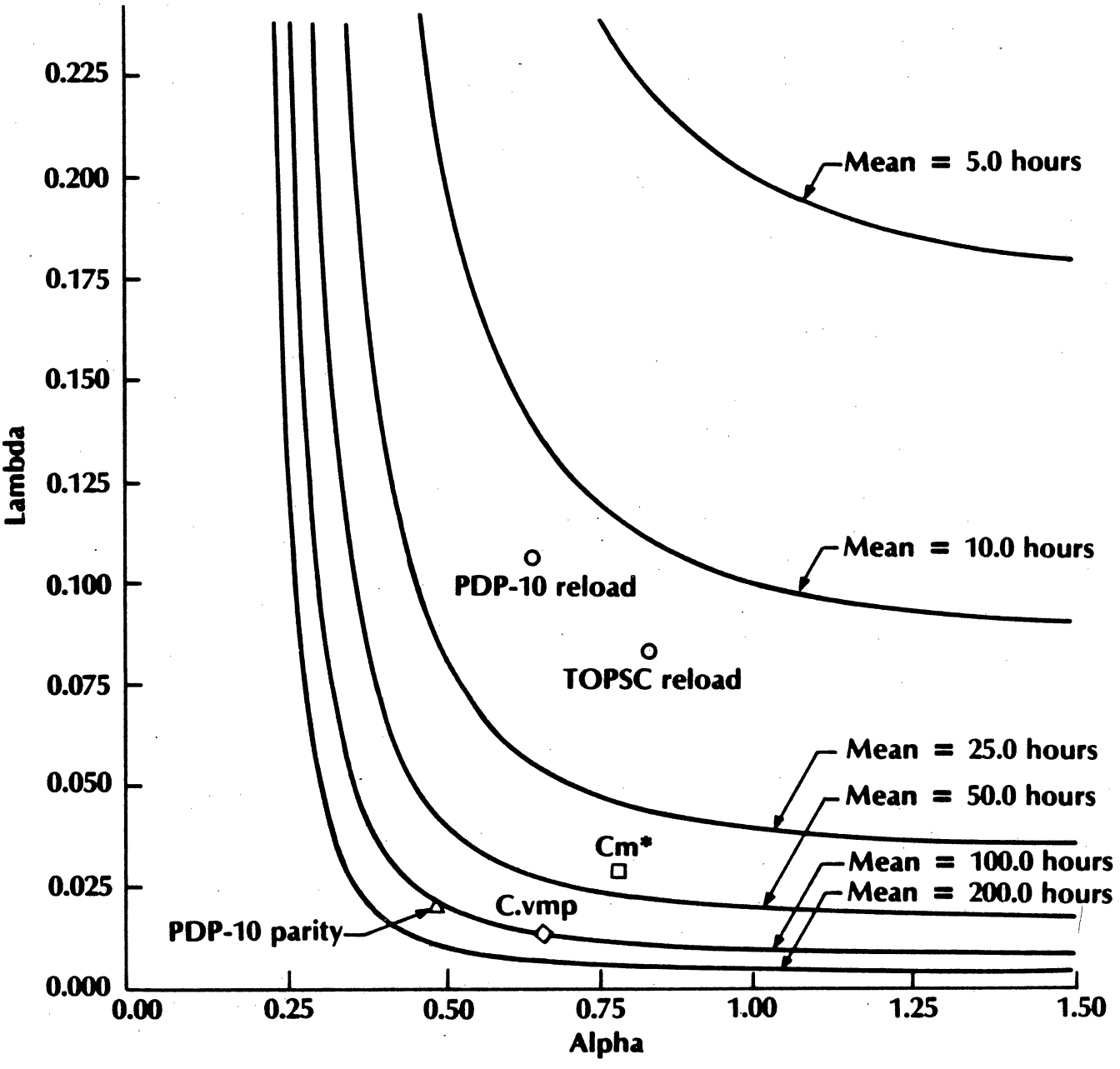


Figure 2–4. Means of Weibull distributions.

IBM 3081 vs KL-10

$\alpha = 0.647$ $\alpha = 0.639$

MTTC = 69.2 hrs MTTC = 13.5 hours

"in only 14% of the errors does the operating system stop processing."

λ_F = Mil 217

$\lambda_E = 20 \lambda_F$

$\lambda_{system} = 3 \lambda_E = 60 \lambda_F$

$\lambda_S = (2 K_{SR} + 1 K_{HR})$

% unsuccessful retry

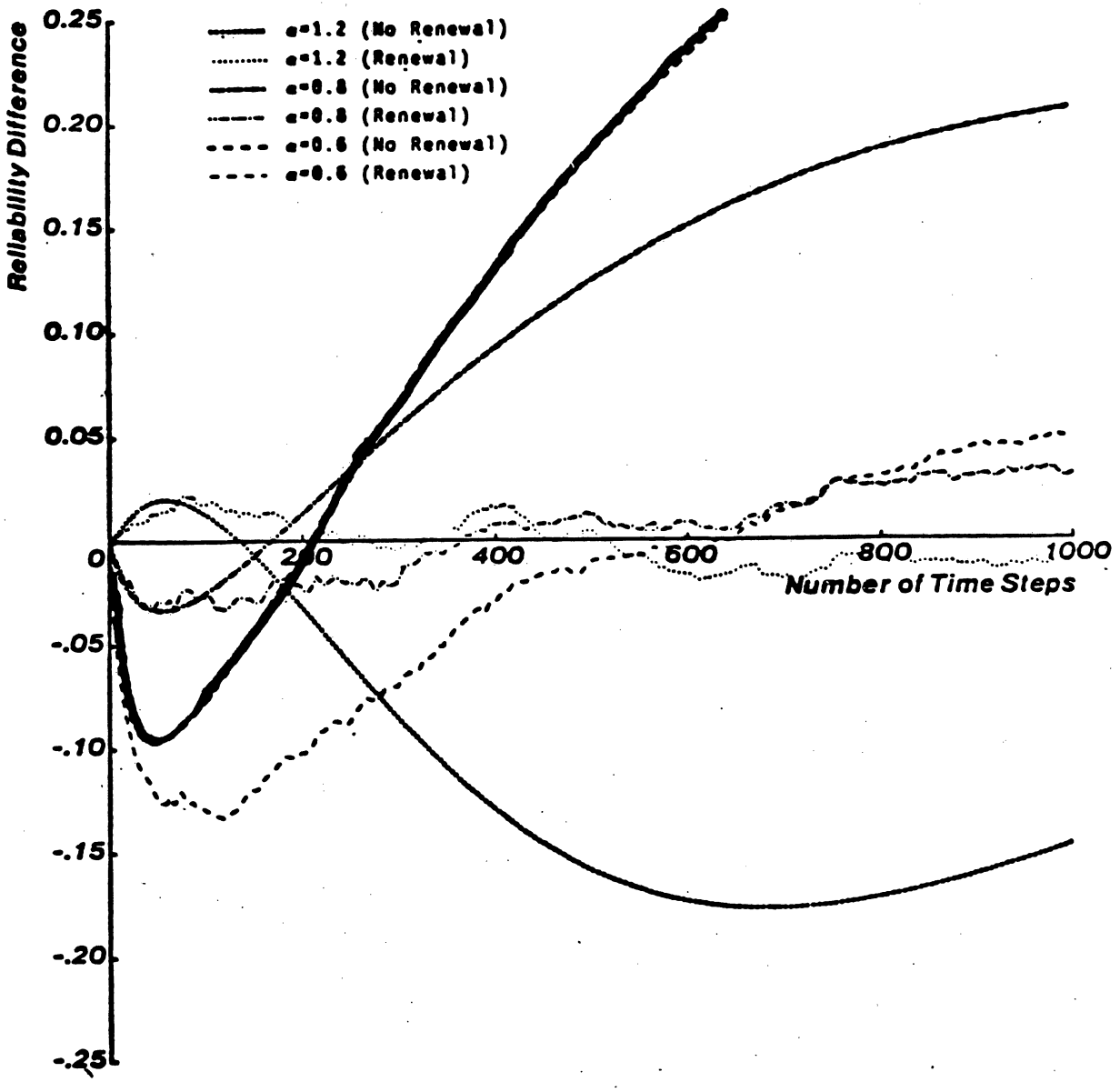


Figure 5-6: Reliability Difference of Duplex System Relative to $\alpha_e = 1.0$

CMU Andrew File Server Study

13 SUN II Workstations

68010 processor

4 Fujitsu Eagles

Observations

21 Workstation years

Number of:

Permanent Failures:	29
Intermittant Faults:	610
Transient Faults:	446
System Crashes:	298

Mean Time to:

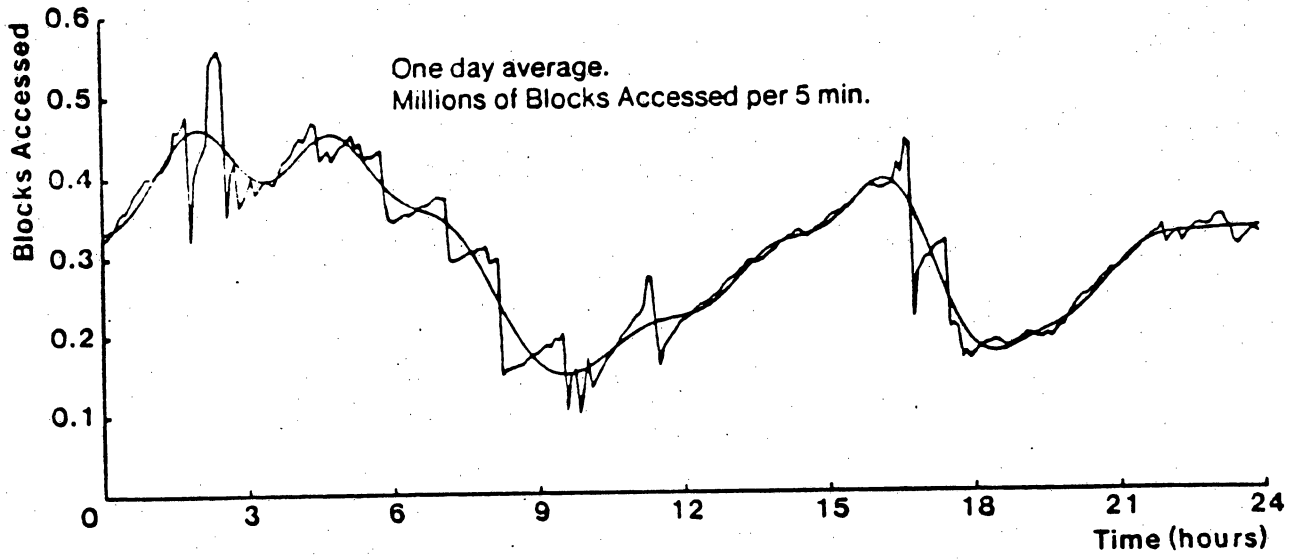
Permanent	6552 hours
Intermittant	58 hours
Transient	354 hours
Crash	689 hours

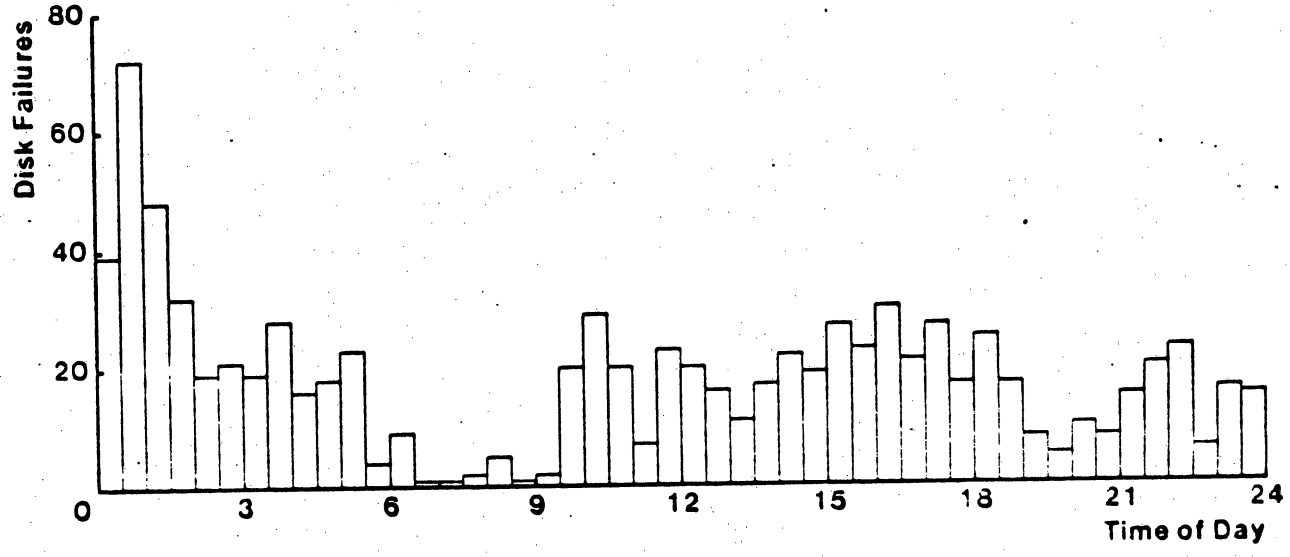
Some Interesting Numbers

- Permament Outages/Total Crashes = 0.1
- Intermittant Faults/Permanent Failures = 21

  Thus first symptom appears over 1200 hours prior to repair
- (Crashes - Permanent)/Total Faults = 0.255
- 14/29 failures had three or fewer error log entries

  8/29 had no error log entries

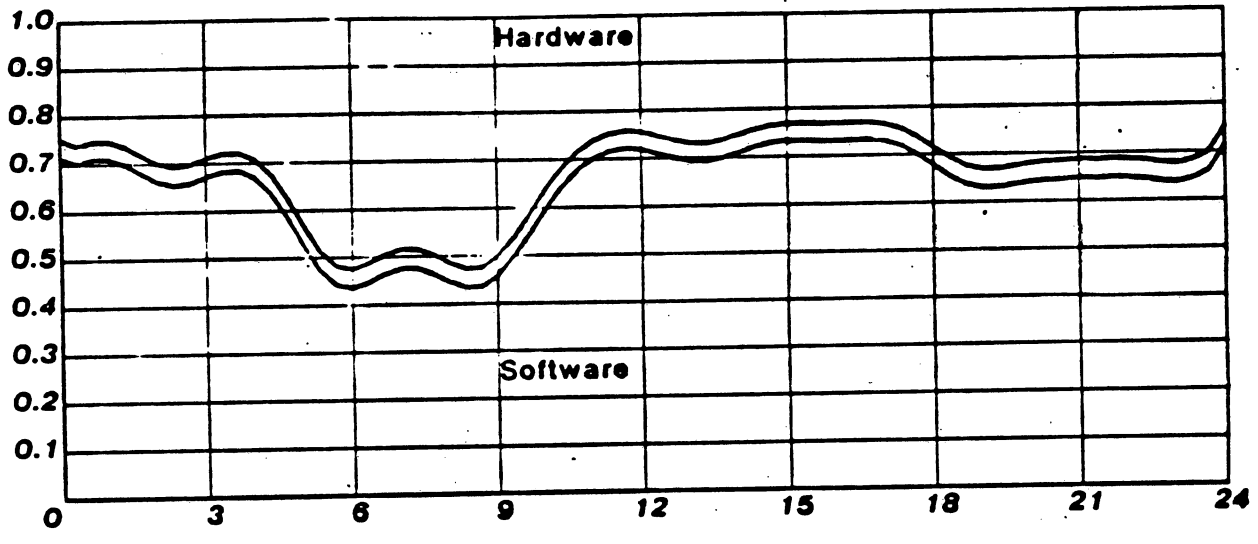

Blocks Accessed
0.6
0.5
0.4
0.3
0.2
0.1
0
One day average.
Millions of Blocks Accessed per 5 min.
3
6
9
12
15
18
21
24
Time (hours)


Disk Failures
80
60
40
20
0
3
6
9
12
15
18
21
24
Time of Day

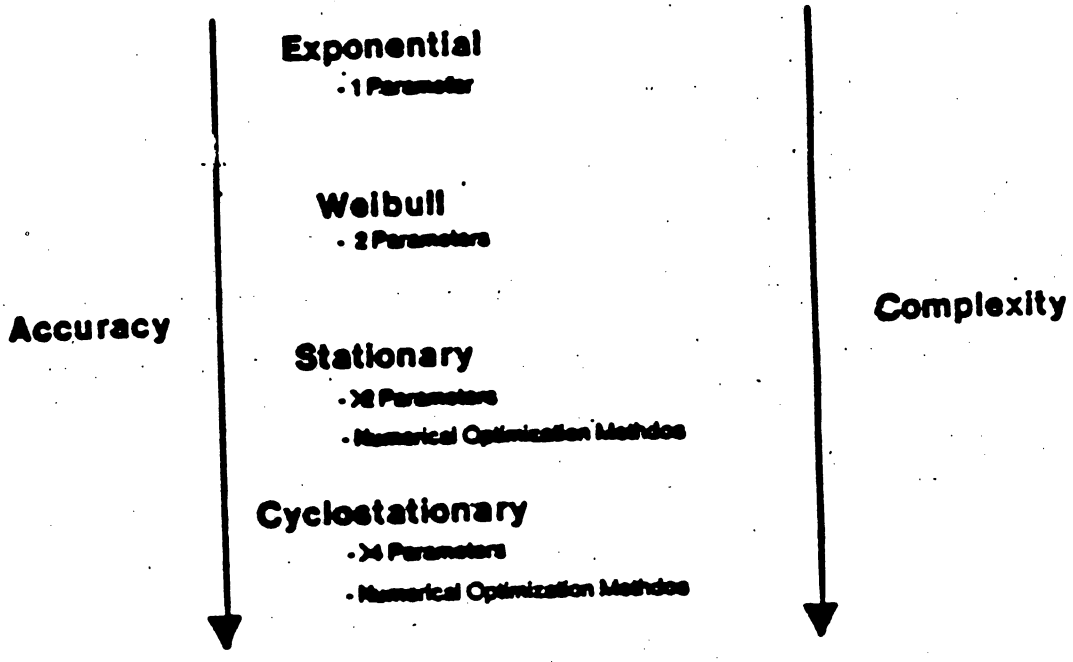
Applications : Software Reliability

- Given that a failure occurs at time t

$$p_{sw}(t) = E\{ \frac{\lambda^{sw}(t)}{\lambda^{sw}(t) + \lambda^{hw}(t)} \}$$



Model Complexity and Accuracy



Hardware Fault Prediction

DESIGN FOR SYSTEM RELIABILITY

4 Hardware fault prediction

OBJECTIVES

* Failure rate predictions
* MTBF predictions
* Availability predictions

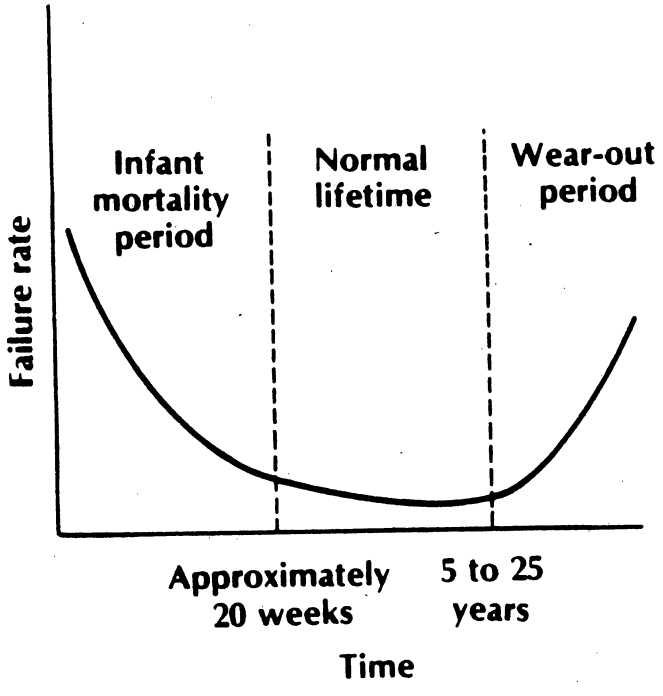


Figure 1–4. Bathtub curve depicting component failure rate as a function of time.

Hazard Function Z(t)

for a known distribution,

$$Z(t) \triangleq \frac{pdf}{1-CDF} = \frac{f(t)}{R(t)}$$

for the type of distributions normally encountered:

$$R(t) = e^{-\int_0^t Z(x)dx}$$

Exponential Distribution (CFR)

$$Z(t) = \lambda$$

Weibull Distribution (IFR, DFR)

$$Z(t) = \alpha\lambda(\lambda t)^{\alpha-1}$$

Poisson Distribution

- Probability of transition from state with N occurrences to state with N + 1 occurrences during time Δt

$$= \beta \Delta t$$

- Occurrences are independent

- Probability of 2 or more occurrences during time Δt is negligible

$$\Rightarrow Pr\{k \text{ occurrences}\} = \frac{\beta^k e^{-\beta}}{k!}$$

$$E[k] = \sum_{k=\phi}^{\infty} k \frac{\beta^k e^{-\beta}}{k!} = \beta = \text{mean}$$

$$Var[k] = E[k^2] - (E[k])^2 = \beta = \text{variance}$$

Note: $Pr\{\phi \text{ occurrences}\} = e^{-\beta}$

Poisson Distribution (cont.)

Substitute constant failure rate λ for β and evaluate at time t.

=> Pr{k failures in time[0,t]} =

$$\frac{e^{-\lambda t}(\lambda t)^k}{k!}$$

(mean = λt
variance = λt)

DEFINITION

Reliability = R(t) =
Pr{0 failures in time [0,t]}

For constant failure rate λ,
$R(t;\lambda) = e^{-\lambda t}$

Poisson Distribution (cont.)

Substitute hazard function Z(t) for β and evaluate at time t

=> Pr{k failures in time [0,t]} =

$$\frac{e^{-\int_0^t z(x)dx}\left(\int_0^t z(x)dx\right)^k}{k!}$$

mean = variance = $\int_0^t z(x)\,dx$

R(t) = Pr{0 failures in time [0,t]} =

$$e^{-\int_0^t z(x)dx}$$

[remember prior definition of Z(x)]

Poisson Distribution (cont.)

Substitute $Z(t) = \alpha\lambda(\lambda t)^{\alpha-1}$ for β and evaluate at time t

=> Pr{k failures in time [0,t]} =

$$\frac{e^{-(\lambda t)^{\alpha}}(\lambda t)^{\alpha k}}{k!}$$

mean = variance = $(\lambda t)^{\alpha}$

R(t) = Pr{0 failures in time [0,t]} =

$$e^{-(\lambda t)^{\alpha}}$$

Component Failure Rates

Component failure distributions are usually assumed to have some sort of "failure rate"

- Constant Failure Rate (CFR)
- Decreasing Failure Rate (DFR)
- Increasing Failure Rate (IFR)
- Nonmonotic Failure Rate?

A time dependent failure rate is called a "hazard function".

$$Z(t)$$

Poisson Distribution: Conclusion

have obtained expressions for

$$\Pr\{k \text{ failures in time } [0,t]\}$$

defined reliability R(t) as

$$\Pr\{0 \text{ failures in time } [0,t]\}$$

Exponential: $Z(t) = \lambda$

$$R(t;\lambda) = e^{-\lambda t}$$

Weibull: $Z(t) = \alpha\lambda(\lambda t)^{\alpha-1}$

$$R(t;\alpha,\lambda) = e^{-(\lambda t)^{\alpha}}$$

General: $Z(t)$

$$R(t;Z(t)) = e^{-\int_0^t Z(\tau)d\tau}$$

Nonredundant System Models

$$R_{sys}(t) = \prod_{i=1}^{n} R_i(t)$$

(assuming independent modules/components)

Exponential: $R_i(t) = e^{-\lambda_i t}$

$$R_{sys}(t) = e^{-\left(\sum_{i=1}^{n} \lambda_i\right) t}$$

Weibull: $R_i(t) = e^{-(\lambda_i t)^{\alpha_i}}$

$$R_{sys}(t) = e^{-\left(\sum_{i=1}^{n} (\lambda_i t)^{\alpha_i}\right)}$$

General: $R_i(t) = e^{-\int_0^t z_i(\tau)\,d\tau}$

$$R_{sys}(t) = e^{-\left(\sum_{i=1}^{n} \left(\int_0^t z_i(\tau)\,d\tau\right)\right)}$$

Parts Count Reliability Model

$$\text{Reliability}(t) = e^{-\lambda t}$$

λ = component failure rate

For a <u>nonredundant</u> system composed of n components:

$$\lambda_{system} = \sum_{i=1}^{n} \lambda_i$$

$$\text{Mean Time To Failure} = \frac{1}{\lambda_{system}}$$

For a general system:

$$MTTF = \int_0^\infty R(t)\, dt$$

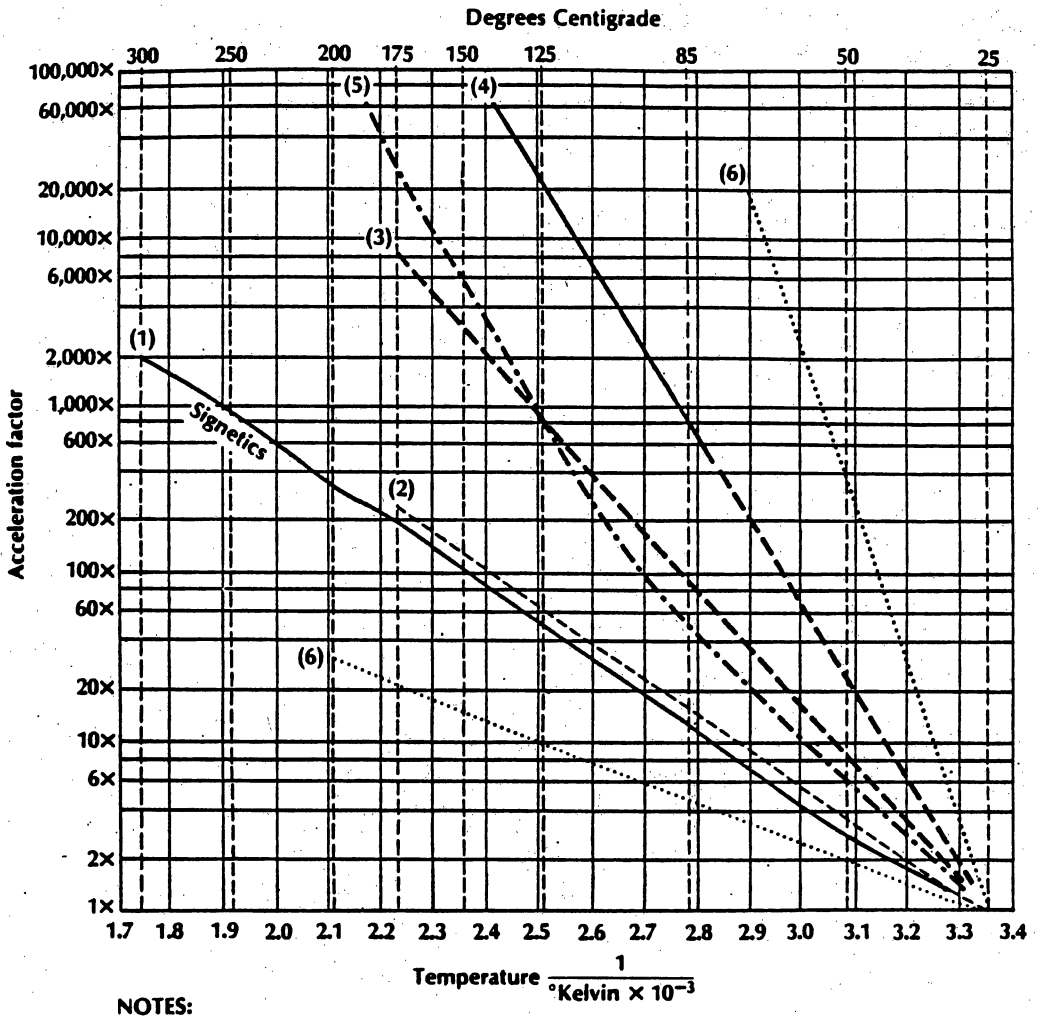
Reliability Modeling Calibration Problems

Components

- Not enough observed failures
  Need 10^7 to 10^8 device hours
- Temperature acceleration testing

System

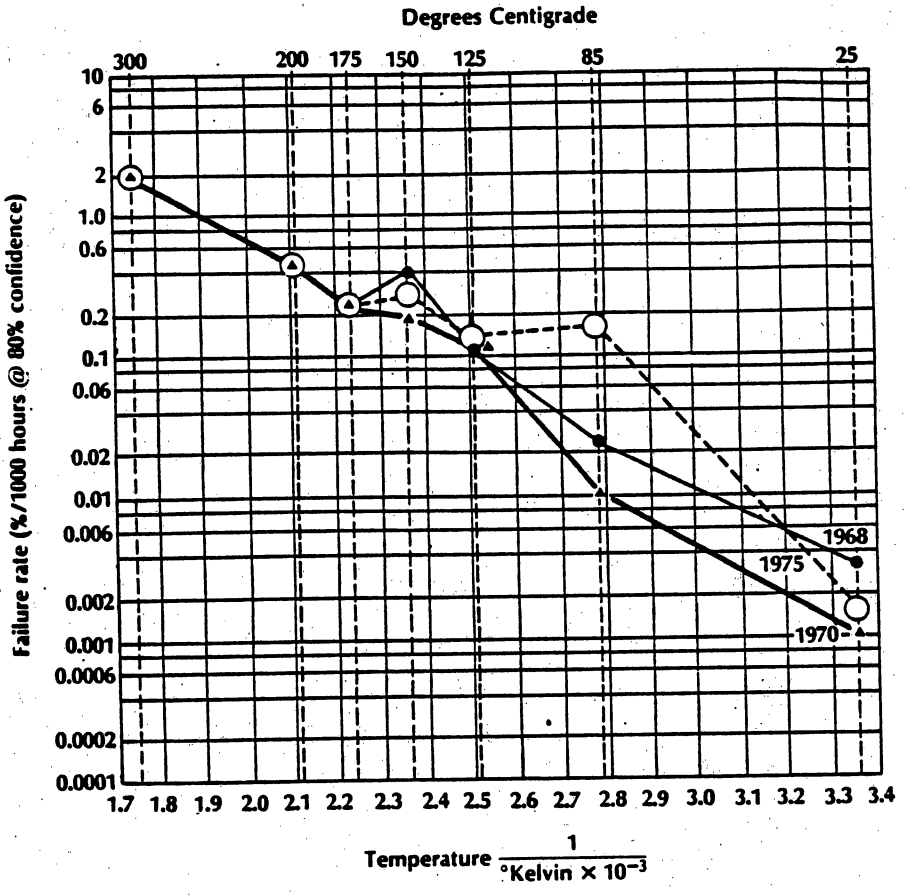
- Environmental factors of individual systems
- Process maturity



NOTES:

1. Calculated from the Signetics Failure Rate vs. Temperature Graph in [Signetics, 1975]. Signetics uses acceleration factors of 15 (for +85°C), 100 (for +150°C), 200 (for 175°C), 350 (for +200°C), 970 (for +250°C) and 2100 (for +300°C) to relate to +25°C equivalent ambient temperature. The +25°C to +125°C segment of the graph is based primarily on operating life data. The segment of the graph above +125°C is based on high temperature storage data. The graph equates to an "activation energy" E_a = 0.41eV.
2. Calculated from MIL-HDBK-217B, 20 September, 1974. Table 2.1.5.4. for π_T vs T_j values. The graph equates to an "activation energy" E_a = 0.41eV and is applicable to all bipolar digital (except ECL) in the normal mode of operation.
3. Calculated from MIL-HDBK-217B, 20 September, 1974. Table 2.1.5.4. for π_T vs. T_j values. The graph equates to an "activation energy" E_a = 0.70eV and is applicable to all MOS, all linear, and bipolar ECL devices in the normal modes of operation.
4. Calculated from MIL-STD-883A, 15 November 1974. Figures 1005-4 and 1015-1 by extrapolating the time temperature regression graph from +78°C back to +25°C. The MIL-STD-883A graph is the Bell Telephone Laboratories graph (Specification A-8-689143, 16 January 1974, etc) and as such applies to storage and operating T_j values and primarily surface inversion failure mechanisms. The graph equates to an "activation energy" E_a = 1.02eV.
5. This curved graph is the result of plotting the "rule of thumb" that failure rates (hence acceleration factors) double for every + Δ 10°C.
6. All competitor data (available to Signetics) produced graphs falling within these two boundaries. The two boundaries equate to "activation energies" E_a = 0.23eV (for lower graph) and E_a = 1.92eV (for the top graph).

Figure 2–5. Failure rate acceleration factor vs. temperature graphs: Signetics and others.



		1968		1970		1975	
		Cat.	Both (●)	Cat.	Both (▲)	Cat.	Both (◯)
HTSL	300°C	2.1	2.1	2.1	2.1	2.1	2.1
HTSL	200°C	0.22	0.48	0.20	0.46	0.2	0.46
HTSL	175°C	0.21	0.29	0.20	0.28	0.2	0.28
HTSL	150°C	0.32	0.40	0.182	0.20	0.155	0.24
HTSL & HTOL	125°C	0.088	0.117	0.101	0.125	0.110	0.147
HTOL	85°C	0.022	0.022	0.013	0.013	0.104	0.160
HTOL	25°C	0.0029	0.0038	0.0011	0.0013	0.0013	0.0017

NOTE:

1. The graphs were constructed to aid in the analysis and dramatization of the effect of the constituent parts of the failure rate equation. All tabulated failure rates were obtained from [Signetics, 1975] by combining life test data for like temperatures. Note that life test results of various die process technologies were indiscriminately summed together for this study.

Figure 2–6. Assessed failure rate vs. temperature graphs from 1963 to 1975 for catastrophic plus degradational failures.

Mil - HDBK - 217

$$\lambda = \pi_L \pi_Q [C_1 \pi_T \pi_V \pi_{PT} + (C_2 + C_3)\pi_E]$$

π_L	- Learning Factor	1, 10
π_Q	- Quality Factor	0.5, 35
π_T	- Temperature Acceleration	0.1, 50
π_V	- Voltage Stress	1, 3
π_{PT}	- PROM Programming Technique	1, 7
π_E	- Environmental Factor	1, 10
C_1, C_2	- Device Complexity	0.001, 0.2
C_3	- Package Complexity	0.02, 0.2

TQ

Level		TQ
S	Mil M-38510, S	0.5
C	Mil M-38510, C	8.0
C-1	Mil STD-883	13.0
D	Commercial, hermetically sealed	17.5
D-1	Commercial	35.0

π_T

$$T_j = T_c + \theta_{Jc} P$$

T_c = case temperature

θ_{Jc} = case thermal resistance

P = worst-case power dissipation

Default θ_{Jc}

Package Type	Number Pins	θ_{Jc}
Hermetic DIP	≤ 22	30
	> 22	25
Nonhermetic DIP	≤ 22	125
	> 22	100

$$\pi_T = 0.1\, e^{\left(-A\left[\frac{1}{T_j + 273} - \frac{1}{298}\right]\right)}$$

TTL, ECL	Hermetic	4635
	Nonhermetic	5214
Low Power Schottky TTL	Hermetic	5214
	Nonhermetic	5794
NMOS	Hermetic	6373
	Nonhermetic	9270

Example Values of π_T

T_J	TTL		LSTTL		NMOS	
	H	NH	H	NH	H	NH
40°C	0.21	0.26	0.26	0.28	0.28	0.44
70°C	0.77	1.0	1.3	1.7	1.7	5.9
90°C	1.6	2.3	3.25	4.6	4.6	26.2

π_V

For CMOS with supply voltage 12 - 15.5V

$$\pi_V = 0.11\, e^{0.168\, V_S\, (T_j + 273)/298}$$

otherwise 1.0

π_{PT}

For bipolar PROM

$$\pi_{PT} = 0.985 + 9.5 \times 10^{-5}(B)$$

π_E

Ground benign =	Computer Room	1.0
Ground Fixed =	Factory Floor	2.5
Ground mobile =	Jeep	4.0
Missile Launch		10.0

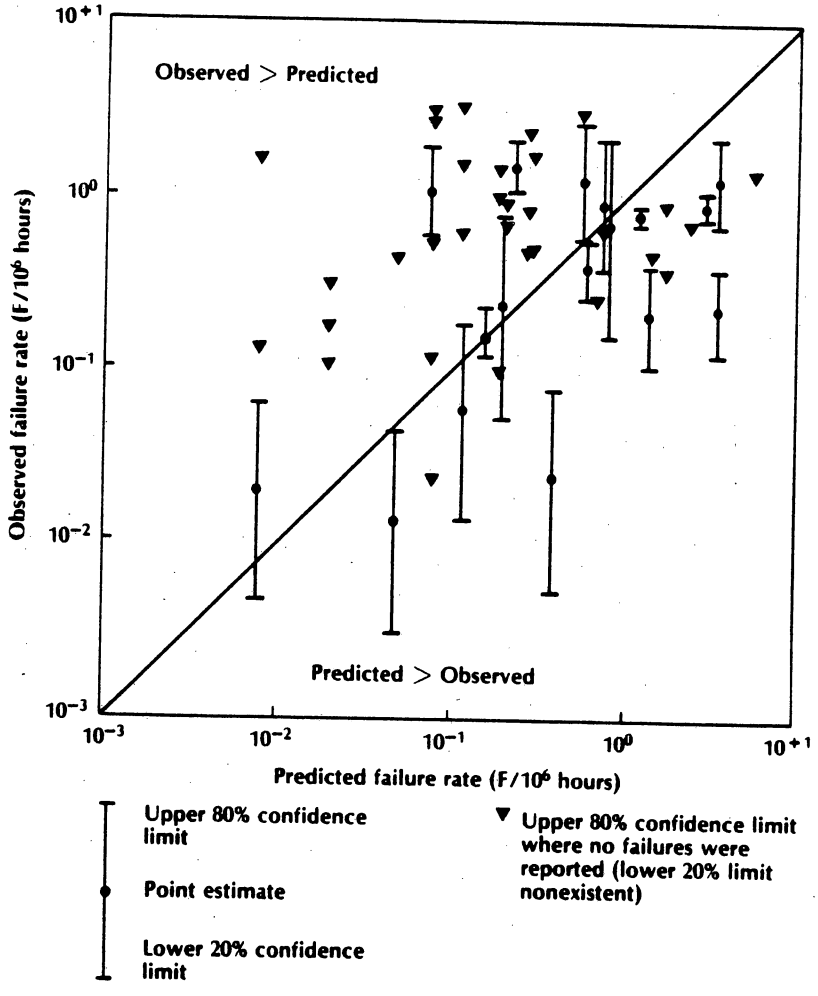


Figure 2–8. Digital-TTL integrated circuit observed vs. MIL-HDBK-217B predicted failure rates of SSI (1-10 gates) and MSI (11-25 gates) complexity.

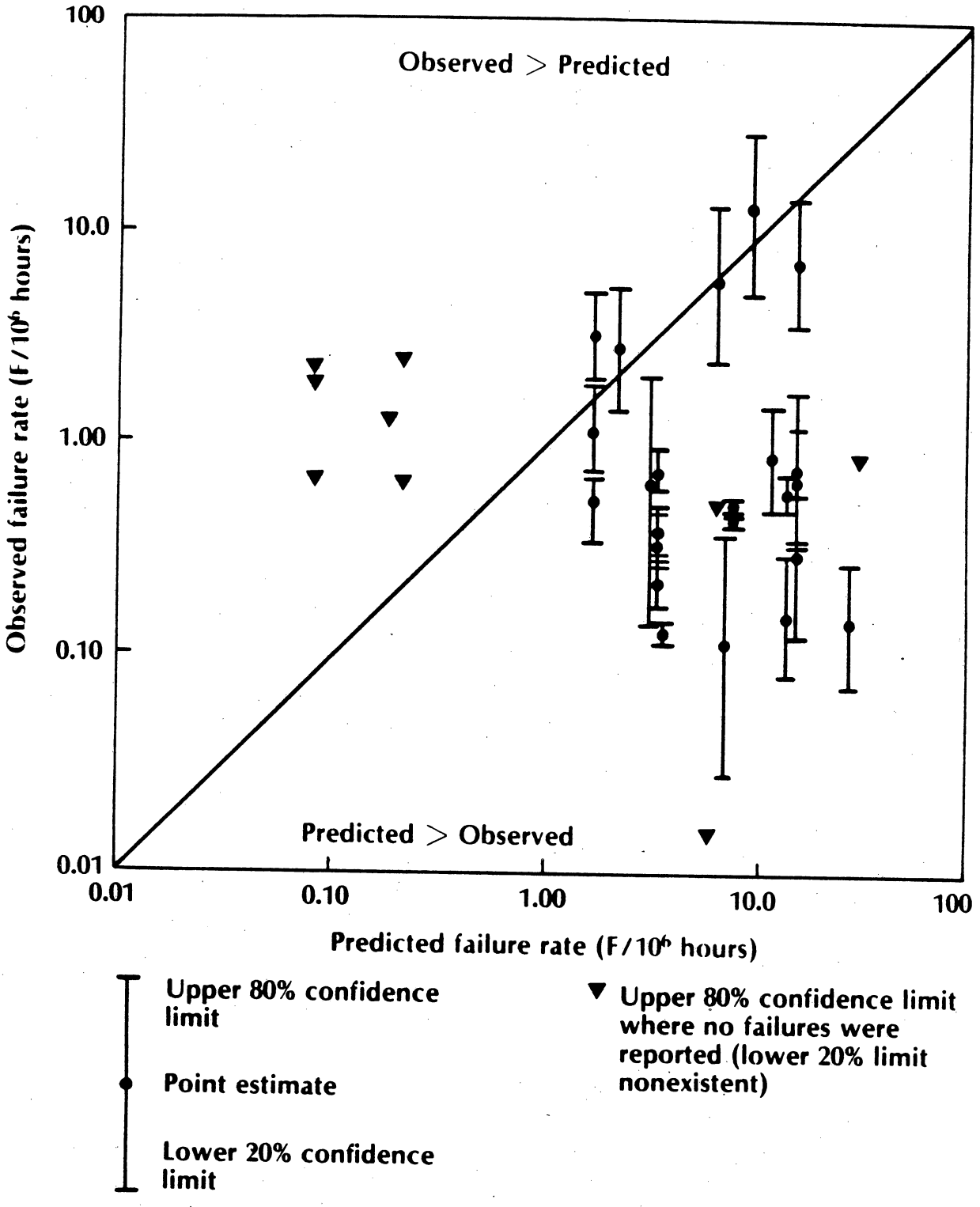


Figure 2–9. Random access memory (RAM) observed failure rates vs. MIL-HDBK-217C predicted failure rates.

Table 2–10. Data from transient errors in a time-sharing file system.

Category	O_i	E_i
0–5	548	429.20
5–10	148	219.15
10–15	63	111.89
15–20	35	57.13
20–25	28	29.17
25–30	18	14.89
30–35	12	7.60
35–40	6	3.88
40–45	3	1.98
45–50	1	1.01
50–55	3	0.5178
55–60	2	0.2639
60–65	1	0.1347
65–70	1	0.06881
70–75	1	0.03514
75–80	1	0.01794
80–85	1	0.009160
85–90	1	0.004690
90–95	1	0.002395
95–100	1	0.001215
100–105	1	0.000627

Table 2–11. Combining categories from Table 2–10.

Category	O_i	E_i	$(O_i - E_i)^2/E_i$
0–5	548	429.20	32.88
5–10	148	219.15	23.10
10–15	63	111.89	21.36
15–20	35	57.13	8.57
20–25	28	29.17	0.04
25–30	18	14.89	0.64
30–35	12	7.60	2.53
35–∞	25	7.93	36.74
		Total χ^2 =	125.86

Table 2–12. Time between crashes for a time-sharing system during one month of operation.

Category (hours)	O_i
0–1	6
1–2	3
2–3	5
3–4	2
4–5	7
5–6	5
6–7	1
7–8	1
8–9	3
9–10	4
10–11	2
11–12	1
12–14	2
14–15	2
15–16	1
16–17	1
17–18	3
18–21	1
21–24	4
24–29	1
29–38	3
38–75	2

Table 2–13. Combining categories from Table 2–12.

Category (hours)	O_i	E_i	$(O_i - E_i)^2/E_i$
0–2	9	9.97	0.09
2–4	7	8.17	0.16
4–6	12	6.79	3.97
6–8	2	5.67	2.37
8–11	9	6.80	0.70
11–15	5	6.66	0.41
15–20	5	5.61	0.06
20–28	6	5.14	0.14
28–∞	5	5.13	0.003
		Total χ^2 =	7.95

Lambda - A Design for Reliability Support Tool

1. *follow design's structure:*
   - systems descriptions top-down
   - analysis outputs display structure
2. *"split" components:*
   - function quantities of a part
3. *failure rates of internal elements of IC's:*
   - not directly, through CUST parts
   - will be added to Lambda in the future.
4. *analyze contribution by part type/number:*
   - SORTKEY, PARTSROLL
5. *accommodate component data hierarchy:*
   - calling parameters
   - part specifications
   - defaults
6. *support for all phases of design:*
   - default parameters
   - "generic" component types,
7. *supply models of standard reliability enhancement techniques:*
   - fault avoidance: MIL-217 models, library function for Θ_{ja}
   - fault detection: not now, can be added through library
   - fault tolerance: table of library functions shown previously
8. *ability to cooperate with other CAE tools:*
   - PRINT command
   - no general reading ability

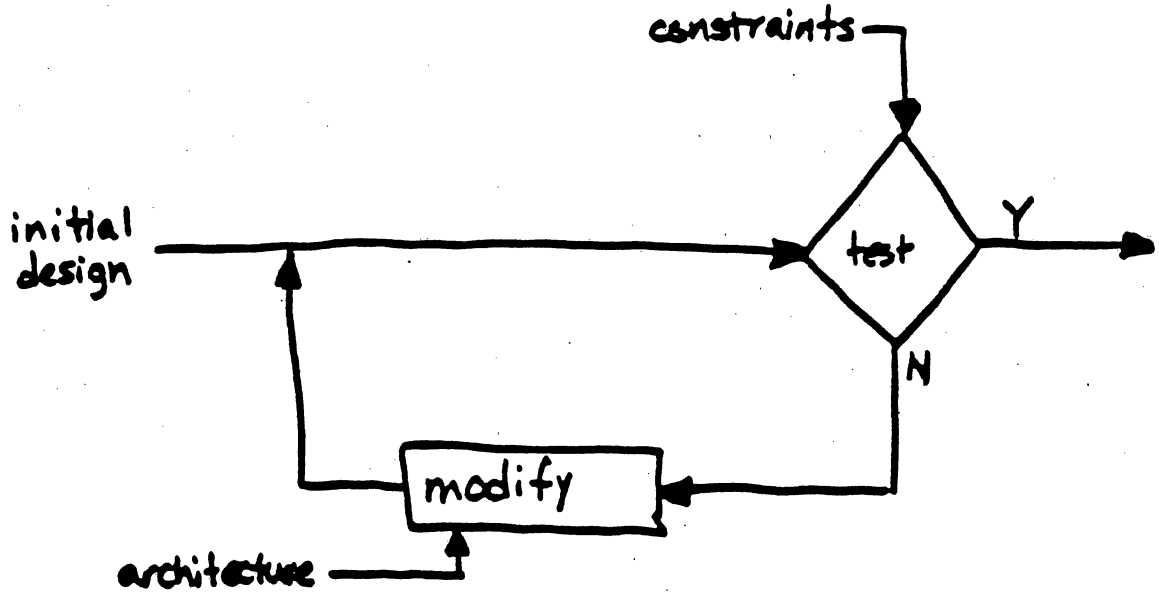
System's Design

DESIGN FOR SYSTEM RELIABILITY

5 System Design

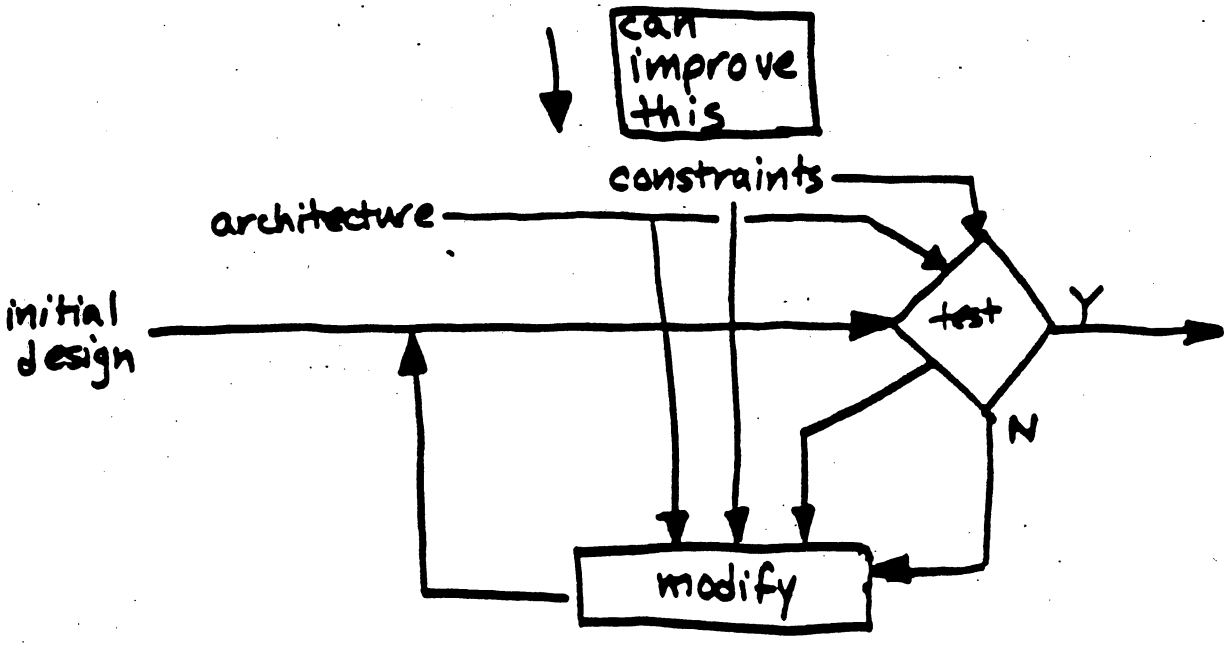
OBJECTIVES

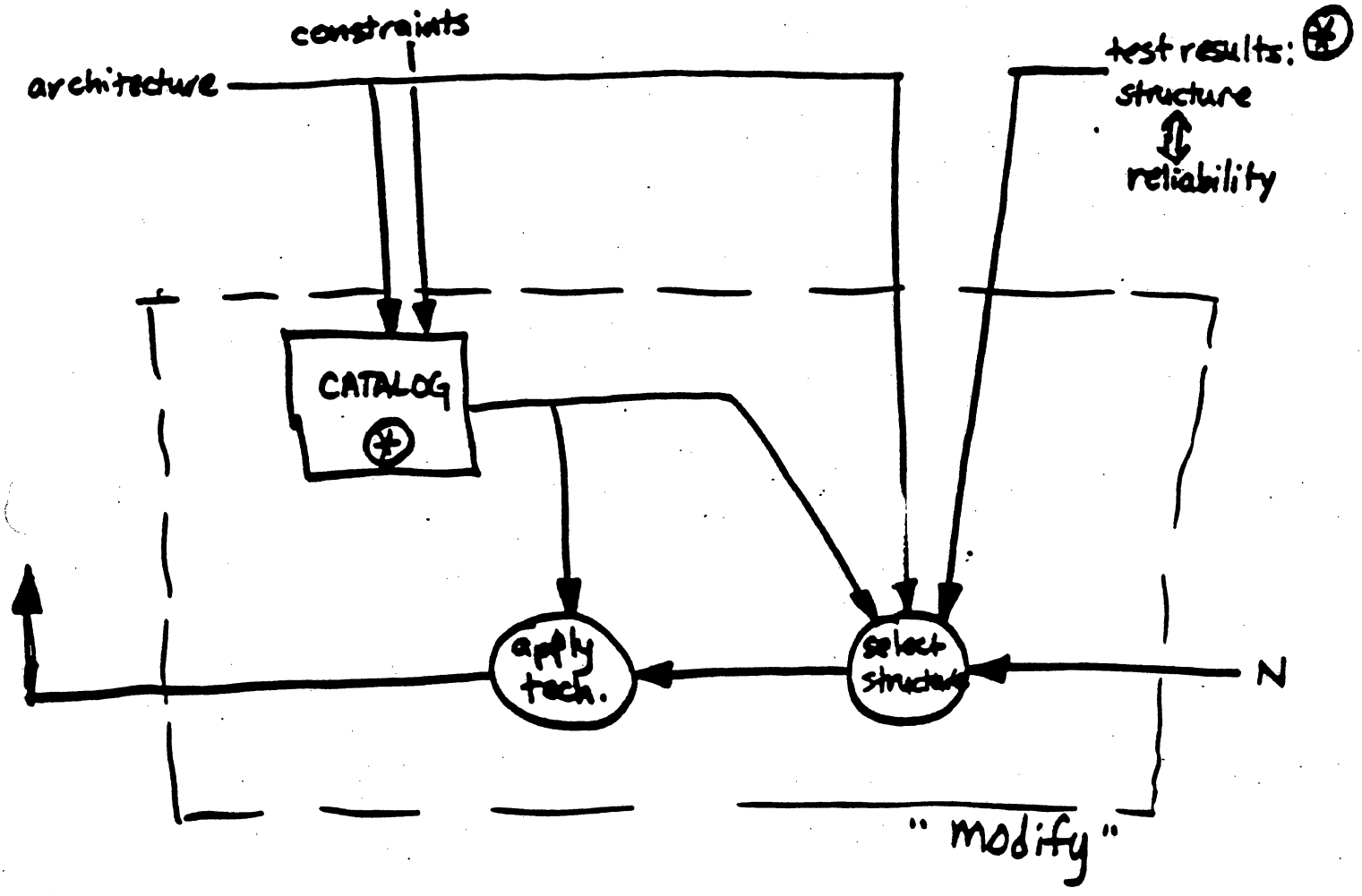
* Translating reliability requirements
* Evaluation criteria for performing design tradeoffs



As done today:

Key point: yes/no test




constraints
architecture
test results:
structure
reliability
CATALOG
apply tech.
select structure
N
"modify"

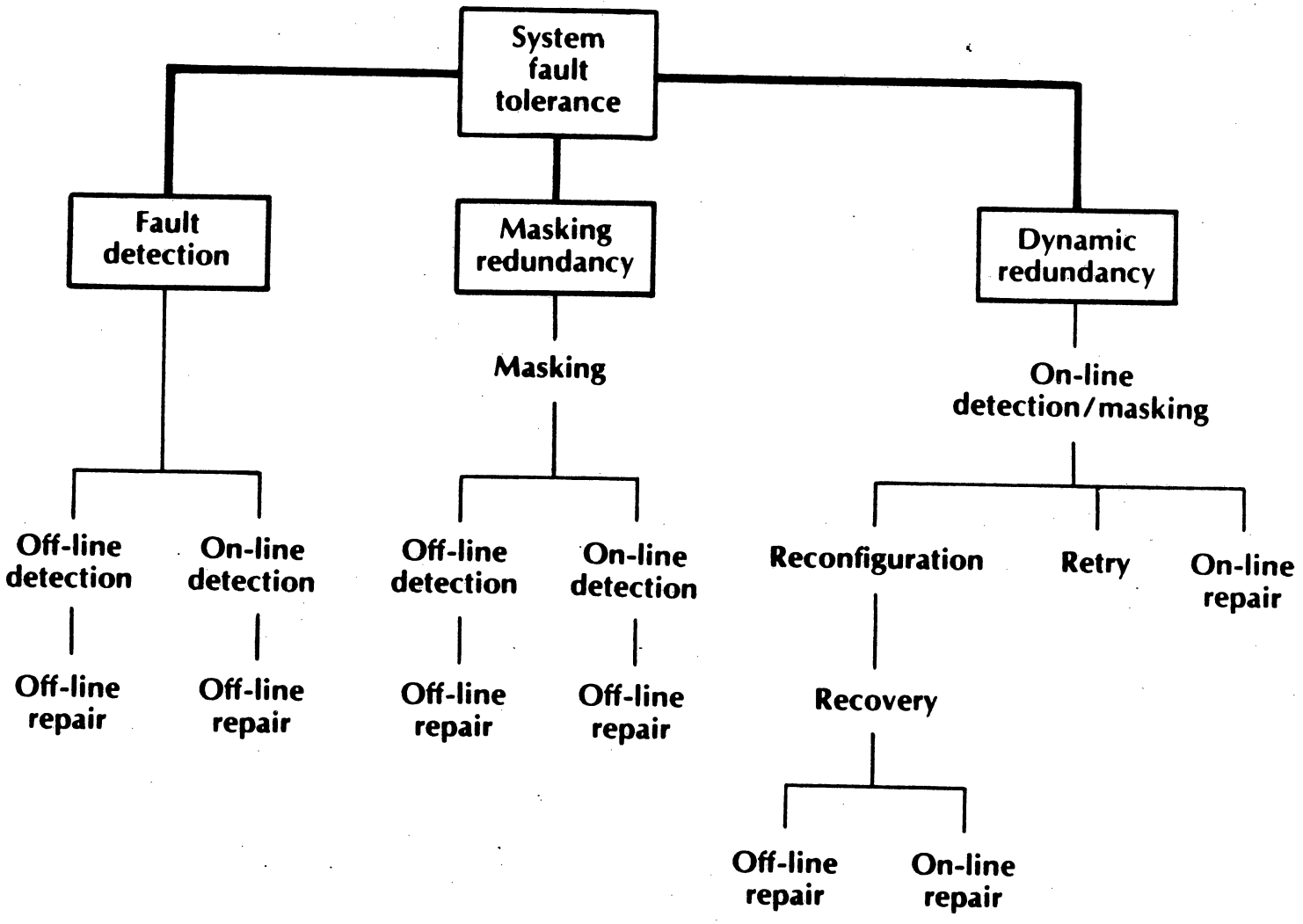
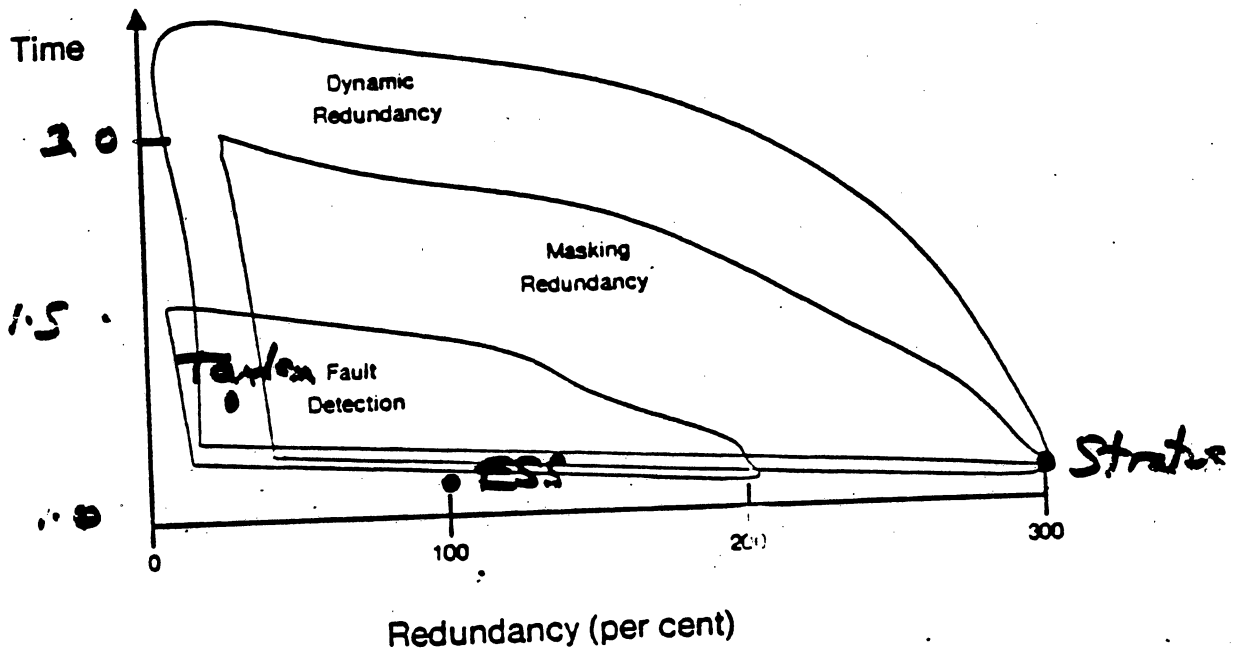


Figure 3–2. Taxonomy of system fault-tolerance strategies.


Time
Dynamic
Redundancy
Masking
Redundancy
Fault
Detection
0
100
300
Redundancy (per cent)

Catalog of Reliability Enhancement Techniques

Region	Technique
Fault Avoidance	Environment Modification Quality Changes Component Integration Level
Fault Detection	Duplication Error Detection Codes > M-of-N codes > Parity Self-checking and Fail-safe logic Watch-dog timers and Timeouts Consistency and Capability checks
Masking Redundancy	NMR/voting Error correcting codes > Hamming SEC DED > Other codes Masking Logic > Interwoven Logic > Coded-state Machines
Dynamic Redundancy	Reconfigurable Duplication Reconfigurable NMR Backup sparing Graceful degradation

Catalog of Reliability Enhancement Techniques

Fault Avoidance - VAX-11/780

Temp °C	π_Q	RAM π_Q	λ (fpmh)	MTTF (hours)	Notes
45	13	13	625.80	1598	Basic Design convection cooling, plastic
40	13	13	516.01	1938	Fans, plastic
35	13	13	423.25	2330	Cabinet ventilation, plastic
45	13	13	506.14	1976	Basic Design convection cooling, ceram
40	13	13	472.53	2116	Fan, ceramic memory chips
5	13	8	494.11	2024	Basic Design
45	8	8	412.20	2426	Basic Design
40	13	8	384.42	2601	Fans, ceramic memory chips
5	8	8	343.41	2912	Fans, plastic
40	8	8	292.06	3424	Fans, ceramic
[illegible]	[illegible]	8	256.65	3942	Ventilation, ceram

Catalog of Reliability Enhancement Techniques (cont.)

Example from Fault Avoidance Area: Summary of PDP-8/e Fault Avoidance Designs

Temp. (^{o}C)	π_Q	RAM π_Q	λ(*fpmh*)	MTTF (hours)	Notes
45	13	13	184.55	5419	Base design, convection cooling, plastic packages
40	13	13	122.75	8147	Fans installed plastic packages
35	13	13	78.10	12804	Cabinet ventilation system plastic packages
45	13	13	47.59	21013	Base design, convection cooling, ceramic packages
40	13	13	44.23	22609	Fans installed, ceramic memory chip packages only
45	13	8	125.73	7953	Base design, convection cooling, plastic packages
45	8	8	113.57	8805	Base design, convection cooling, plastic packages
40	13	8	37.23	26858	Fans installed, ceramic memory chip packages only
45	13	13	165.23	6052	Bit slice design, convection cooling, plastic packages
45	13	8	69.45	14398	Bit slice design, fans installed, plastic packages

Error detection codes

A systematic application of redundancy to information

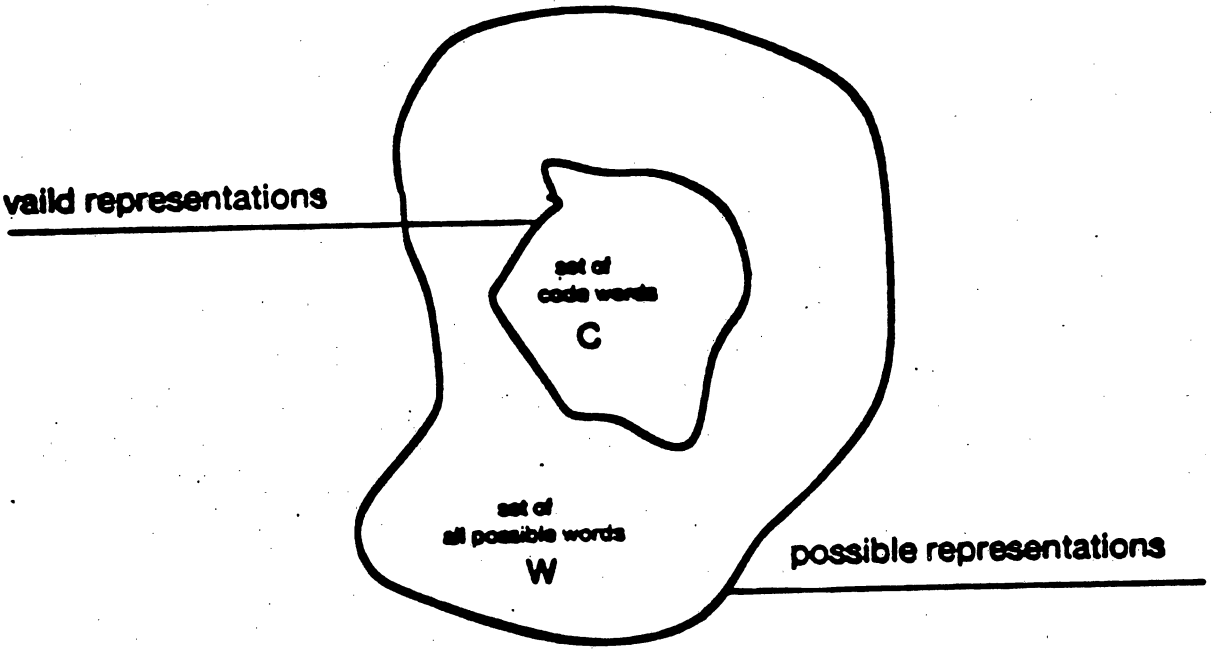
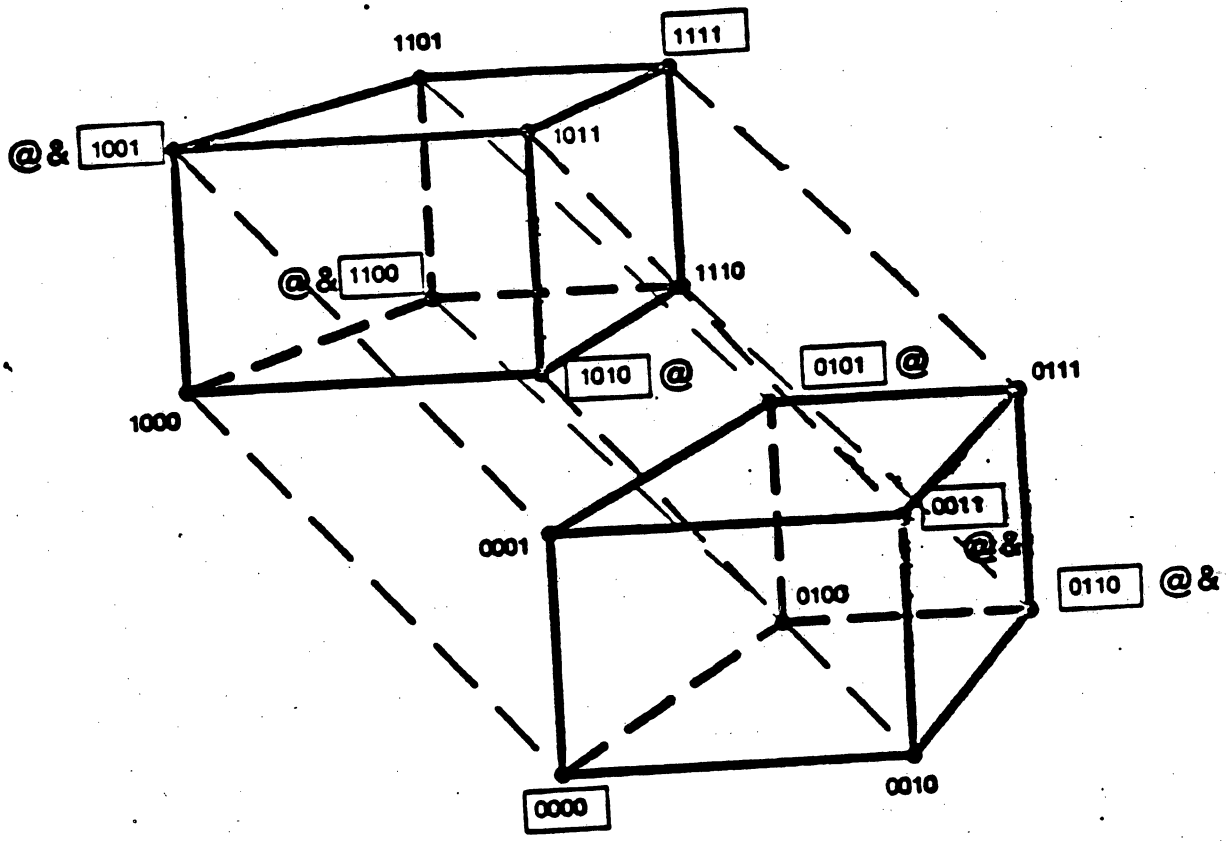


Figure <code space> The set of invalid representations (i.e. non-code words) is W-C

Measurement:

- { Hamming distance ↘ sometimes
  Coverage
  Redundancy (& cost)
- usually, both are needed



Figure<distcubebigger> Expanded cube made by adding one more bit to the word size. Boxed words are even parity words, @ marks a code word in a 2/4 m-of-n code, and & marks code words from the complemented duplication code used as an example in the text. The unmarked words are odd parity code words.

The previous code had minimum distance of 2

- it's duplication, or a variant
- unlike straight duplication has coverage of all unidirectional errors
- distance not enough

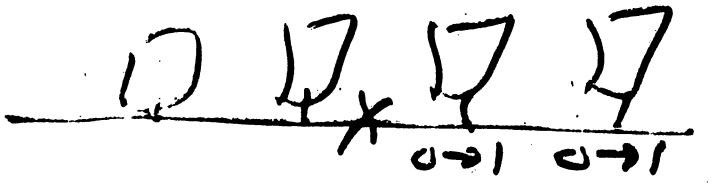
aim is code efficiencies:

1. minimum redundancy
2. maximum coverage, distance
3. minimum coding/detection/decoding hardware, time

Separable codes
(n,k)

Properties of Codes

Code	Bits in word	Code Words	Distance	Single Bit	Double Bit	0's	1's	Multiple Adjacent Unidir. Errors
CD	4	4	2	✓	66%	✓	✓	✓
3/4	4	6	2	✓	33%	✓	✓	✓
Even Parity	4	8	2	✓	0	✗	✗	✗
Odd Parity	1	8	2	✓	0	✓	✓	✗



Application dependencies:

1. Decoding, etc. serial
   parallel
   speed
2. Code invariance to data operation
3. Fault types prevailing

Codes can be modified to meet constraints.

M-of-N CODES

N bits/word $(a_o a_1 \ldots a_{n-1})$

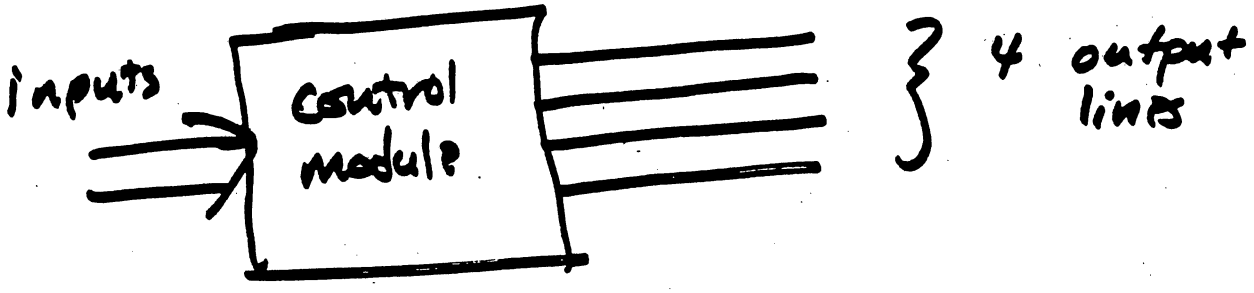
$$\sum_{0}^{N-1} a_i = M$$

- single & unidirectional faults.
- complex decoding unless serial
- simple
- large amount of redundancy need ${}_nC_m$ code words

Common use - control circuitry
3/5 ex. (15)

Bell ESS-3a 4/8

M/N EXAMPLE



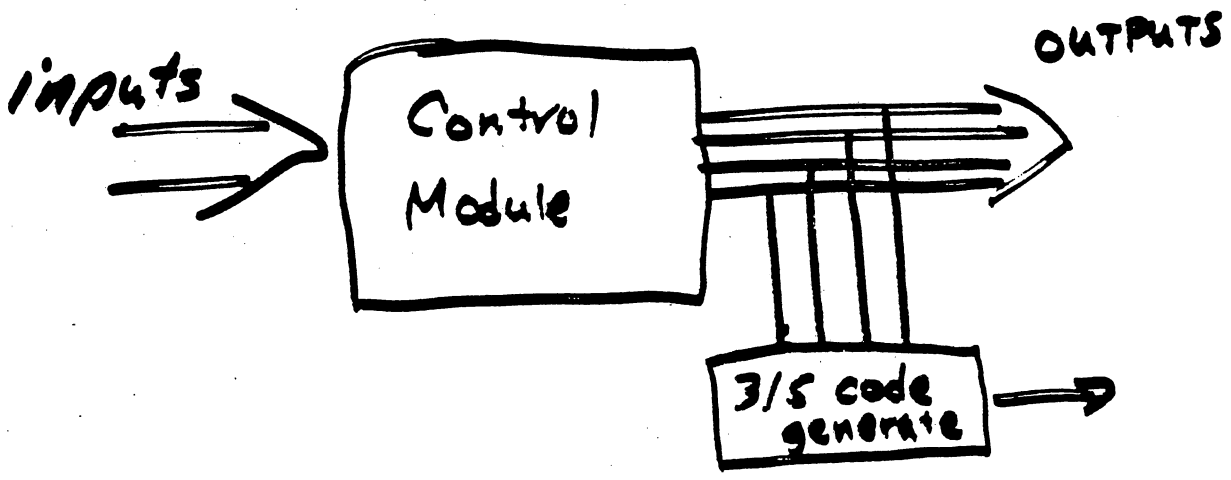
possible outputs @ any one time

1001	1011
1010	1110
1100	1101
0110	0111

Note that 3 ≥ n ≥ 2 lines set at any one time.

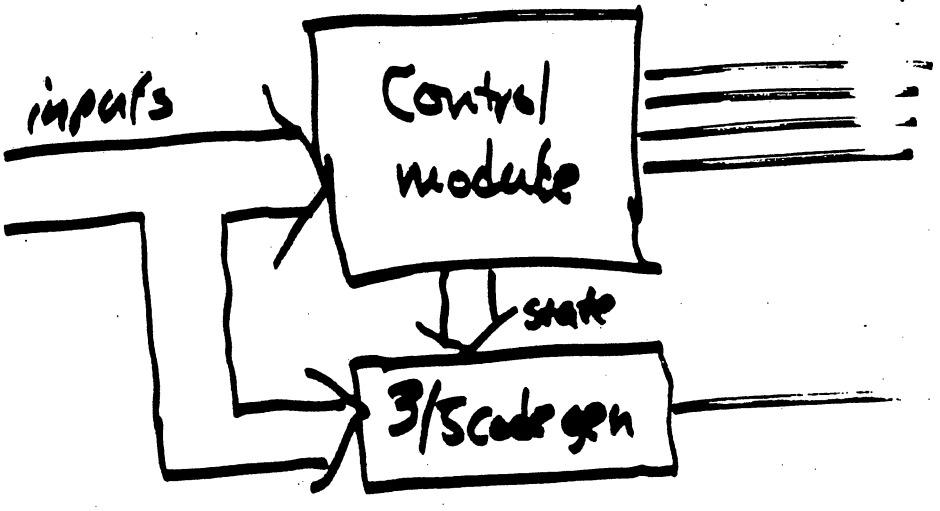
use an extra line to give a separable

3/5 code


inputs
Control
Module
OUTPUTS
3/5 code
generate

No! Does not check module function!

Instead:



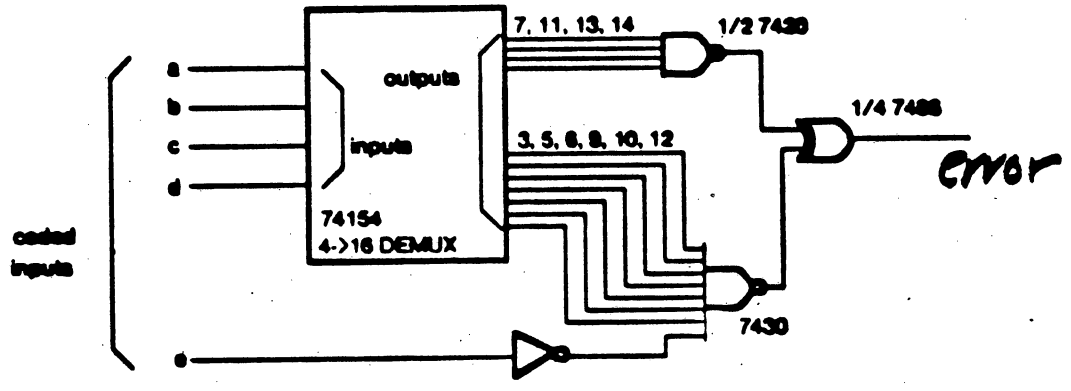


Figure <3/5 detect> Simple 3/5 code error detector

PARITY CODES

- Linear separable codes
- Parity - odd or even
- Generation by b - bit XOR gate or parity tree
  $\lceil \log_2 b \rceil$ gate levels
- Decoding uses b + 1 - bit tree
- Bit/word
- Bit/byte
  - varying parity sense
    - C.mmp shared memory
- Interlaced parity
- Chip wide parity (special case of interlaced parity)

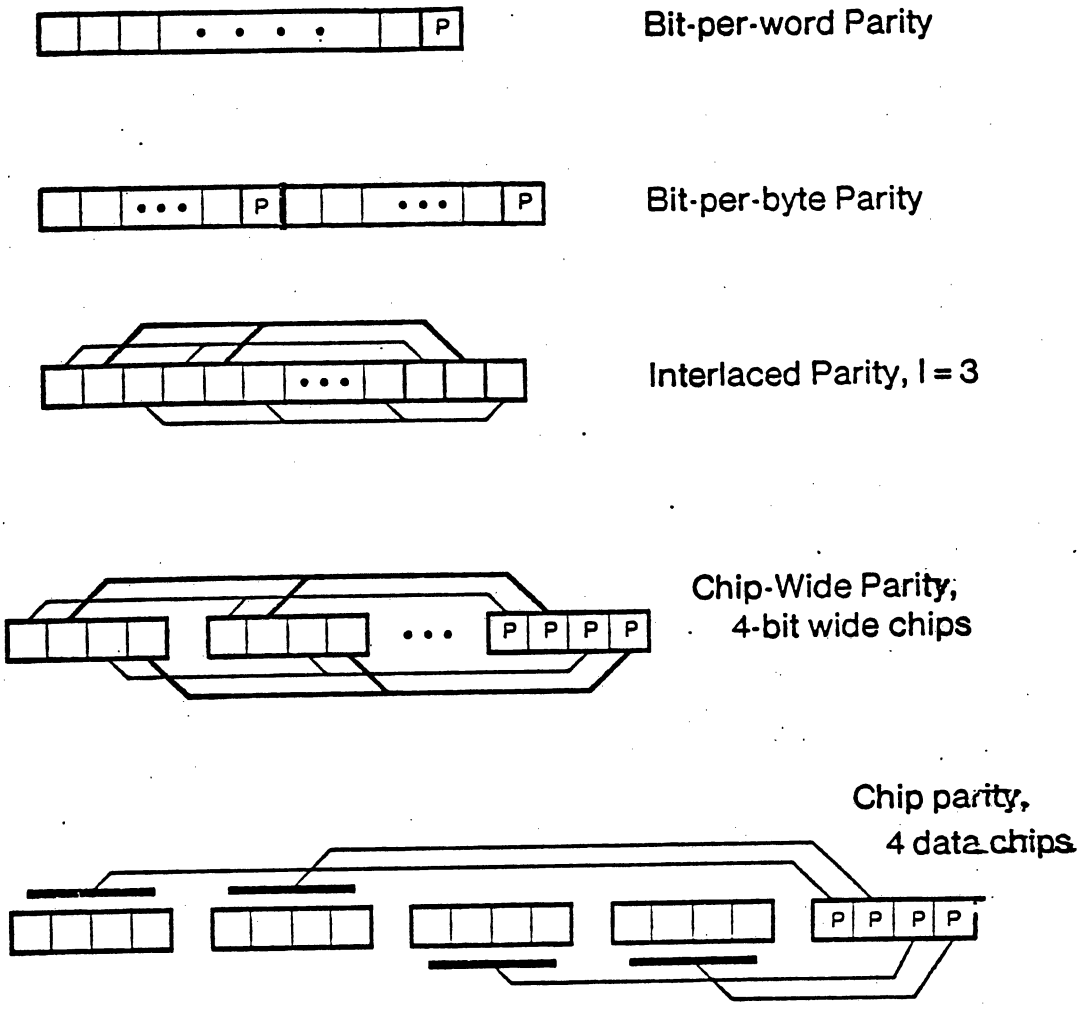


Figure <parity schemes> Examples of five different parity schemes.

	Redundancy (fraction of extra hard-ware)	Cost (number of inputs to parity tree)	Performance (number of levels of parity tree)	Diagnostic Resolution
Parity Bit per Word	1/b	b+1	$\lceil \log_2 b+1 \rceil$	word
Parity Bit per Byte	1/m	$\frac{b}{m}(n+1)$	$\lceil \log_2 m+1 \rceil$	byte
Inter-laced Parity	i/b	(b/i)+1	$\lceil \log_2 (\frac{b}{i}+1) \rceil$	group

m bits/byte

i parity groups

CHECK SUMS

- Cheap
- Performed over a block of 5 words
- Contiguous blocks - block Xfer devices best, since updating awkward - busses, tapes, disks .....
- Low diagnostic resolution

Four types

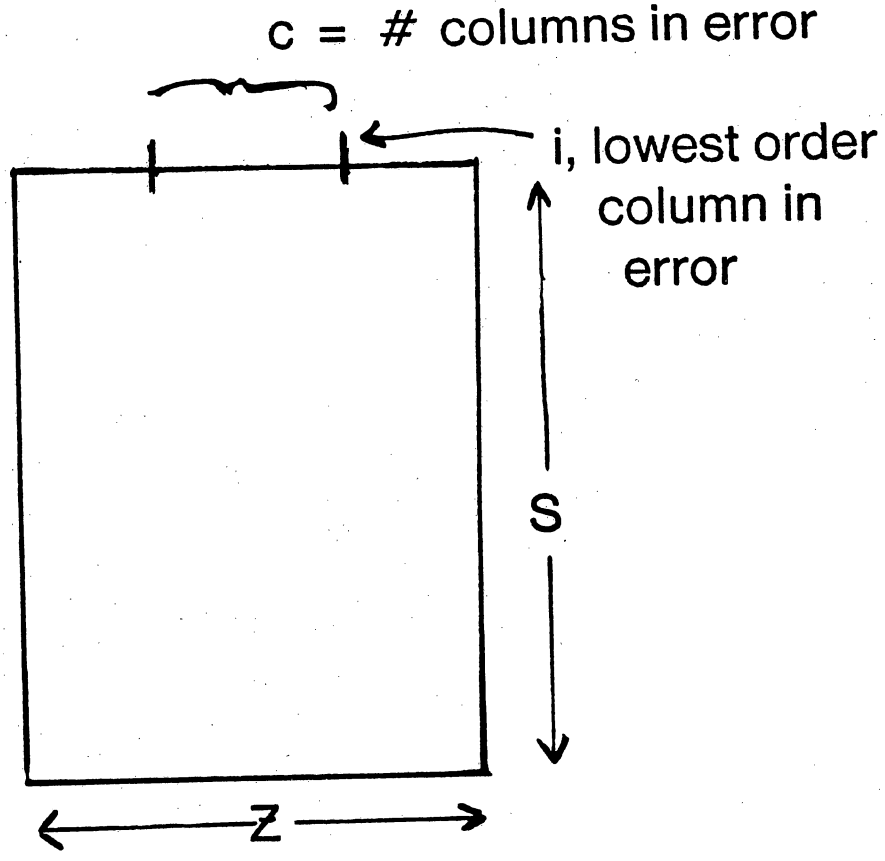
single precision: Z bits/word module 2^z addition

- error coverage varies with bit position - best in LSB

extend precision - module $2^z + \leftarrow\leftarrow$ addition

- extra bits in check sum store
- $S<2^a$ coverage same for all columns

CHECK SUMS



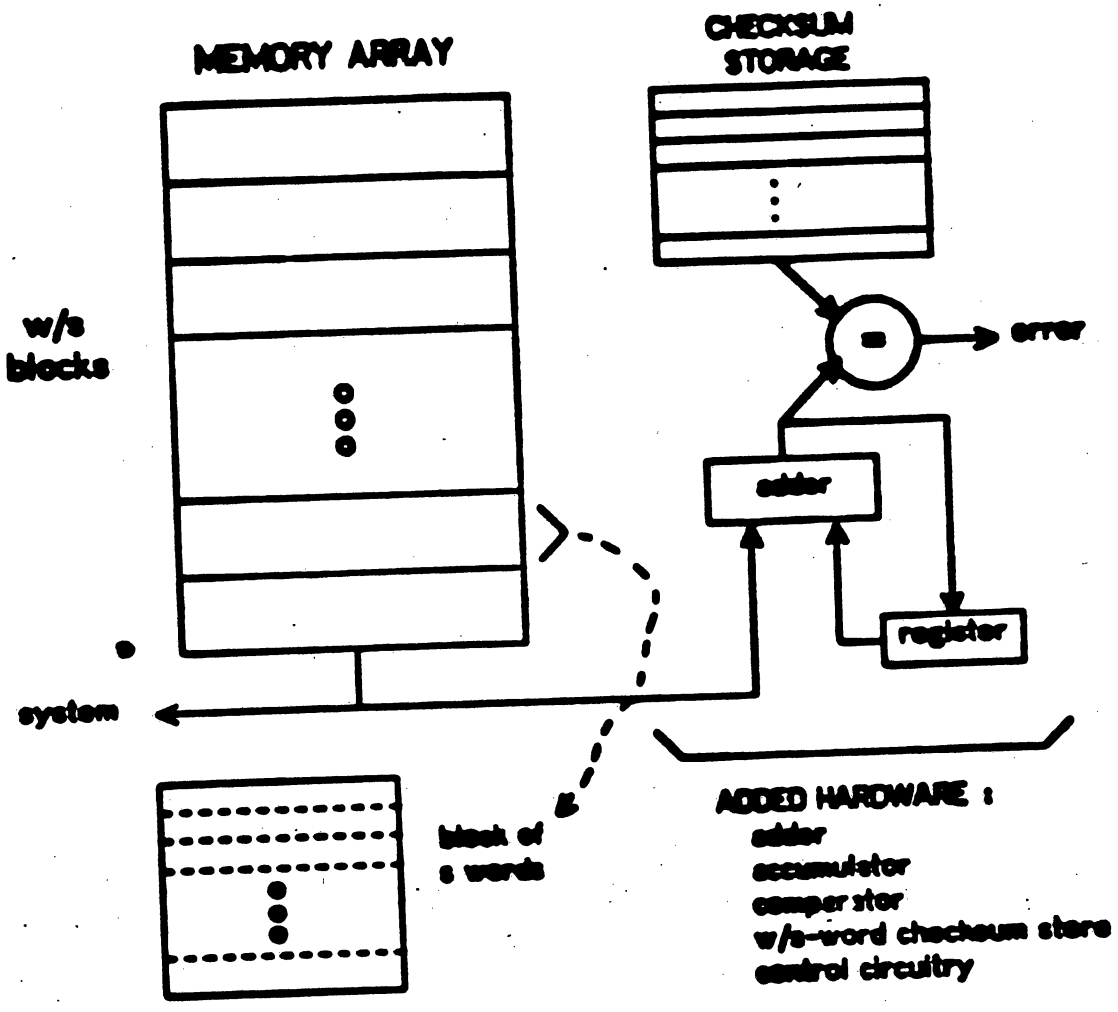


Figure 3.1 Memory with Checksum Error Detection

CHECK SUMS
(continued)

Honeywell checksum - modified double precision

adjacent words concatenated before addition

- overflow and loss of info

Low-cost residue codes

adder with end-around carry

Probability of Detection with Single Precision Checksum

Error Types	Coverage Ratio	Condition
Single Device - multiple word		
- Single column	1	$i < z - \log_2 s$
	$(1 - 2^{-s})$	$i = z - \log_2 s$
	$(1 - 2^{-s}(1 + C_{s/2}))$	$i = z - \log_2 s + 1$
	$1 - 2^{-(z-i)} + 2^{-s})$	otherwise
- Multiple adjacent columns	1	$i \leq z - \log_2 s - c$
	$1 - 2^{-(z-i)} + 2^{-cs}$	otherwise
Multiple Device		
- Single word	1	
- Multiple word adjacent columns	$1 - 2^{-cs}$	$i \leq z - \log_2 s - c$
	$1 - 2^{-(z-i)}$	otherwise

Probability of detection of errors through Honeywell Checksum

Error Types	Coverage Ratio	Condition
Single Word	1	
Multiple Word		
Single Column	1	$i < z - \log_2(s/2)$
	$(1-2^{-(s+1)})$	$i = z - \log_2(s/2)$
	$(1-2^{-s}(1+{}^{s/2}C_{s/4}))$	$i = z - \log_2(s/2) + 1$
	$(1-2^{-(z-i+(s/2))}+2^{-s})$	Otherwise
Multiple Column	1	$1 \le z - \log_2(s/2) - c$
	$(1-2^{-(z-i+(\frac{s}{2}))}+2^{-cs})$	Otherwise

ARITHMETIC CODES

$C(A*B) = C(A) * C(B)$

invariance w.r.t. *

- usually ~~on~~ invariant w.r.t * ≠ not all operations needed (e.g. logic)

Simplest are AN codes:

$C(A) = aA$
where $a \neq 2^n$

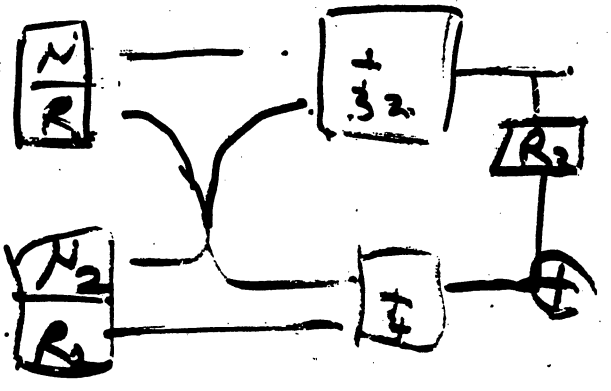
Simplest AN code:
$C(A) = 3N$

Residue Codes (Separable)

N	R(N)

Residue - M code word

$R(n) = N \bmod M$



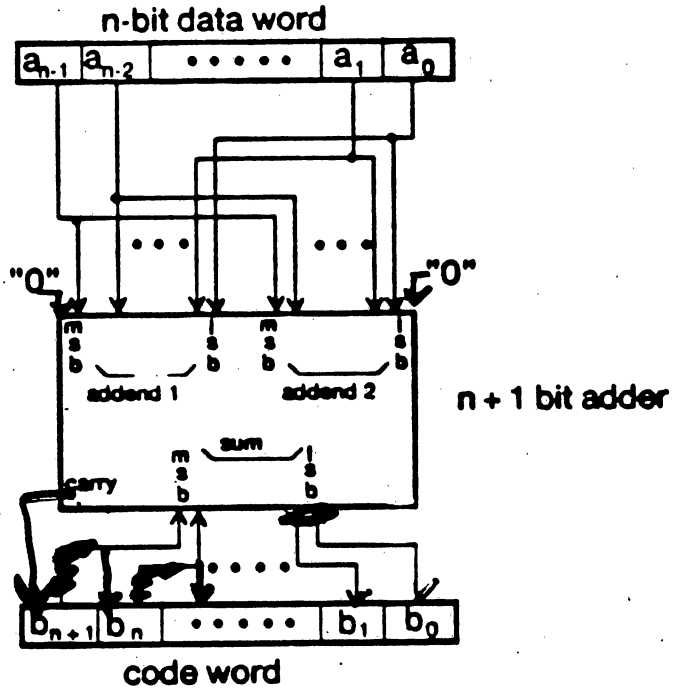
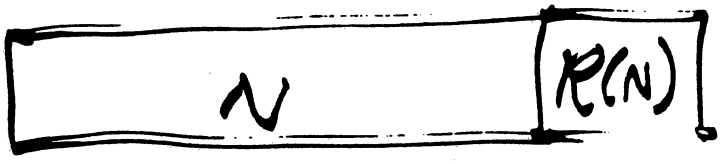


Figure <AN coder> Simple Encoder for 3N Single Error Detecting Arithmetic Code

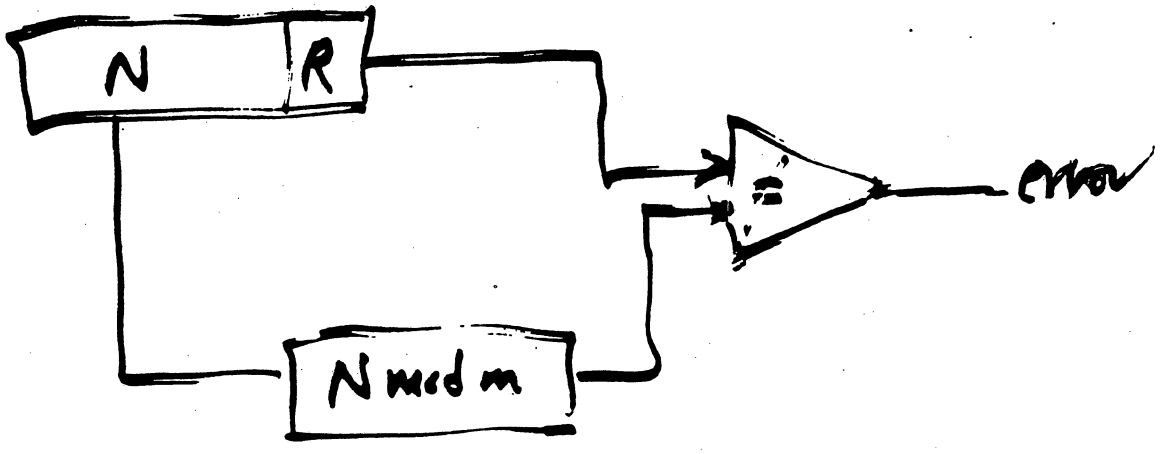
Residue Code

Residue - m

$R(N) = N \bmod m$



separable



CYCLIC CODES

(n,k) cyclic codes can detect bursts $\leq$ [redacted] $(n-k)$ bits in length.

(n,k) = (r + k,k), where r is # of check bits

Cyclic Codes uniquely specified by a Generator Polynomial

$$G(x) = X^r + a_{r-1}X^{r-1} \ldots + a_1X + a_0$$

a_i = (0,1) for binary codes

Cyclic codes normally done in serial in a linear feedback shift register, but can be done in parallel (e.g. $\exists$ decoder matrix). In serial version, though, data length k is arbitrarily long, albeit usually a multiple of character length.

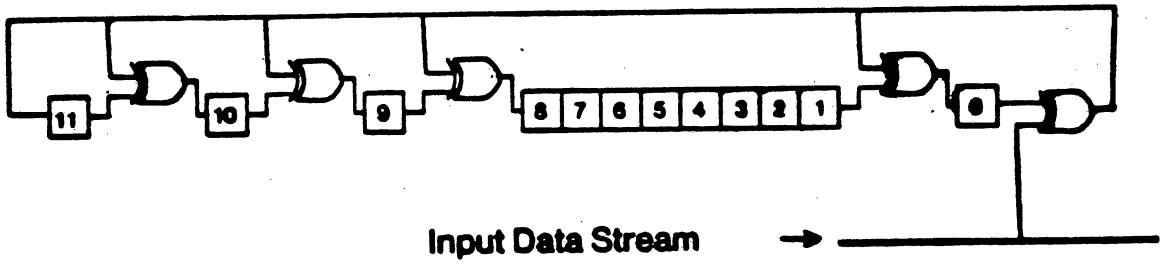
Example G(x)'s

CRC-12 $X^{12} + X^{11} + X^3 + X^2 + X + 1$

CRC-16 $X^{16} + X^{15} + X^2 + 1$

CRC-CCITT $X^{16} + X^{12} + X^5 + 1$

Detects bursts ≤ 16 bits
99% of bursts > 16 bits
ANSI X.25



Generator Polynomial $G(X) = X^{12} + X^{11} + X^3 + X^2 + X + 1$

Figure <CRC-12> Block Check Register for CRC-12 Cyclic Code

Place XOR at output of cell i

for $i = r - j$

$r = 12$, $j = 13, 11, 3, 2, 1$

$(12+k, k)$ code

Detects bursts of length 12 or less

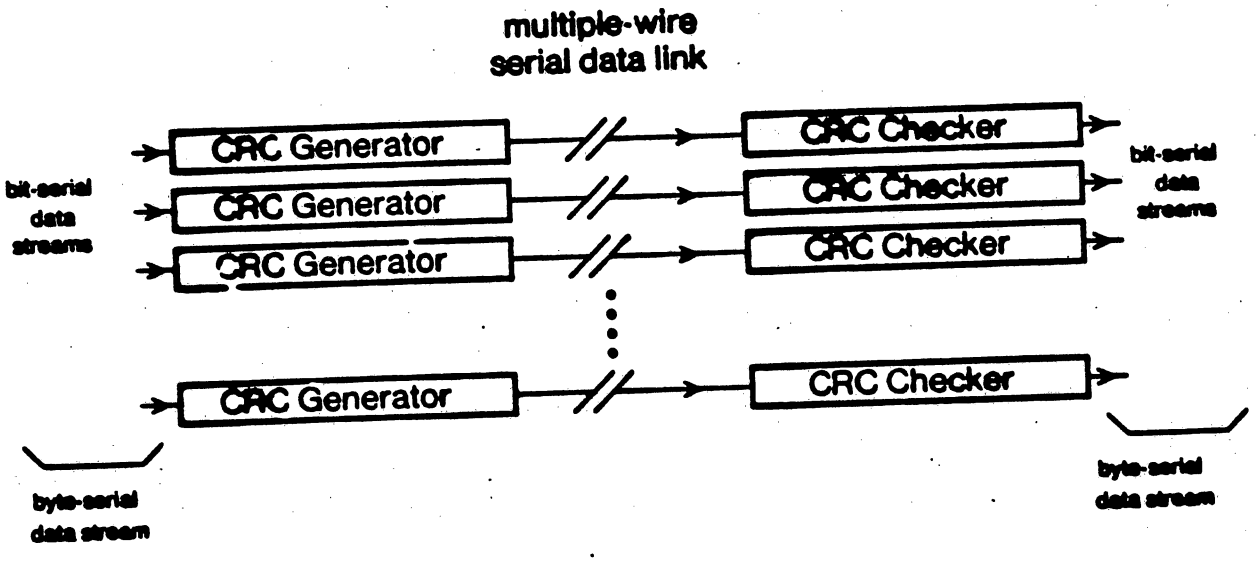


Figure <Multiple CRC> Use of cyclic codes for a bus which transfers data in a byte-serial fashion, i.e., the bits of each byte are transmitted simultaneously. The CRC check bits are generated for each bit stream during the duration of the block transmission and are appended at the end of the block.

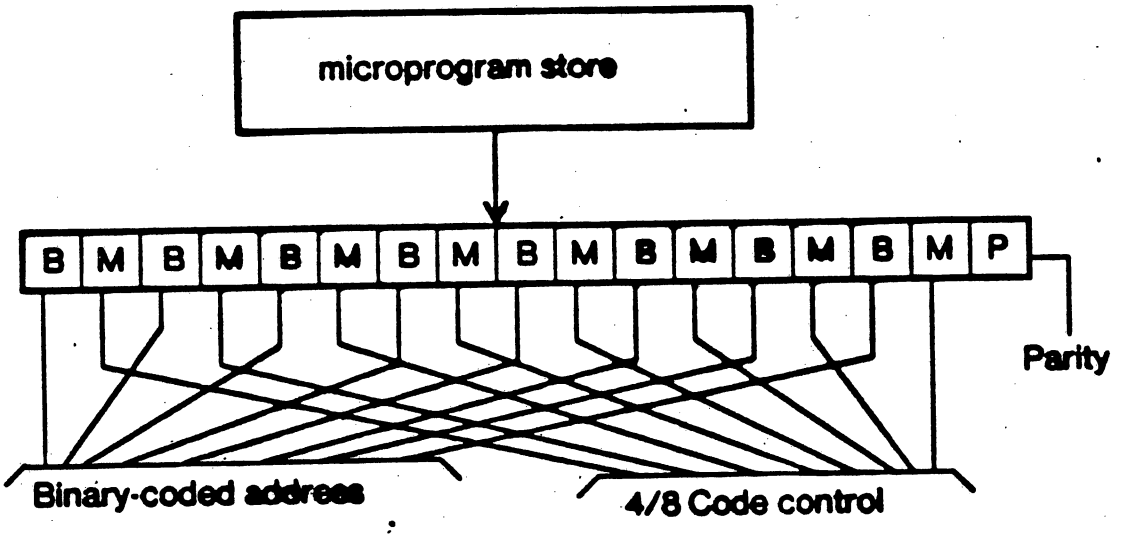


Figure (ESS-3A) 4/8 coding in Bell ESS-3A microstore. The control bits are 4/8 coded, and interlaced with the address bits. This scheme protects the address bits as well as the control bits from multiple adjacent unidirectional errors. (Source [TOY 78])

Duplication

- Two copies, Compare
  - disagreement indicates error.

    - cheap (comparison)
      twice $ + comparison
    - easy to implement
    - little perf. degr.
      - comparator
      - synch. delay

Coverage:
- All single failures (exc. comparator)
- Many multiple", as long as at least one non-overlapping

Variants of Duplication

1. Increase coverage

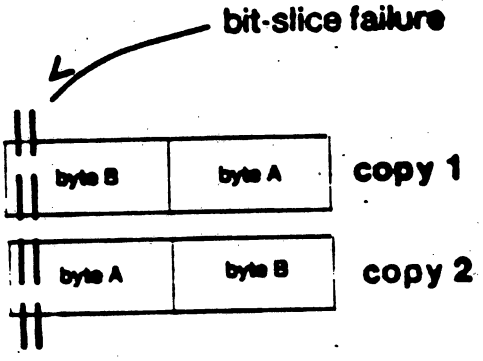
- swap & compare - C.mmp (→)
- dual-diversity
  - logical dual implementation (→)
  - "on-set" & "off-set" implementations
  - different algorithms

2. Application levels

- Bus (module) level (Univac 1100/60 X→)
- register (ESS-1)
- processor (AXE)

3. Cost

- Duplicate tasks, and do only part of processing in duplicate (TANDEM)
  coverage↓ cost ↓ perf ↑
- Time redundancy
  coverage ↓↓ cost ↓ perf ↓



C.mmp, used for critical control data structures

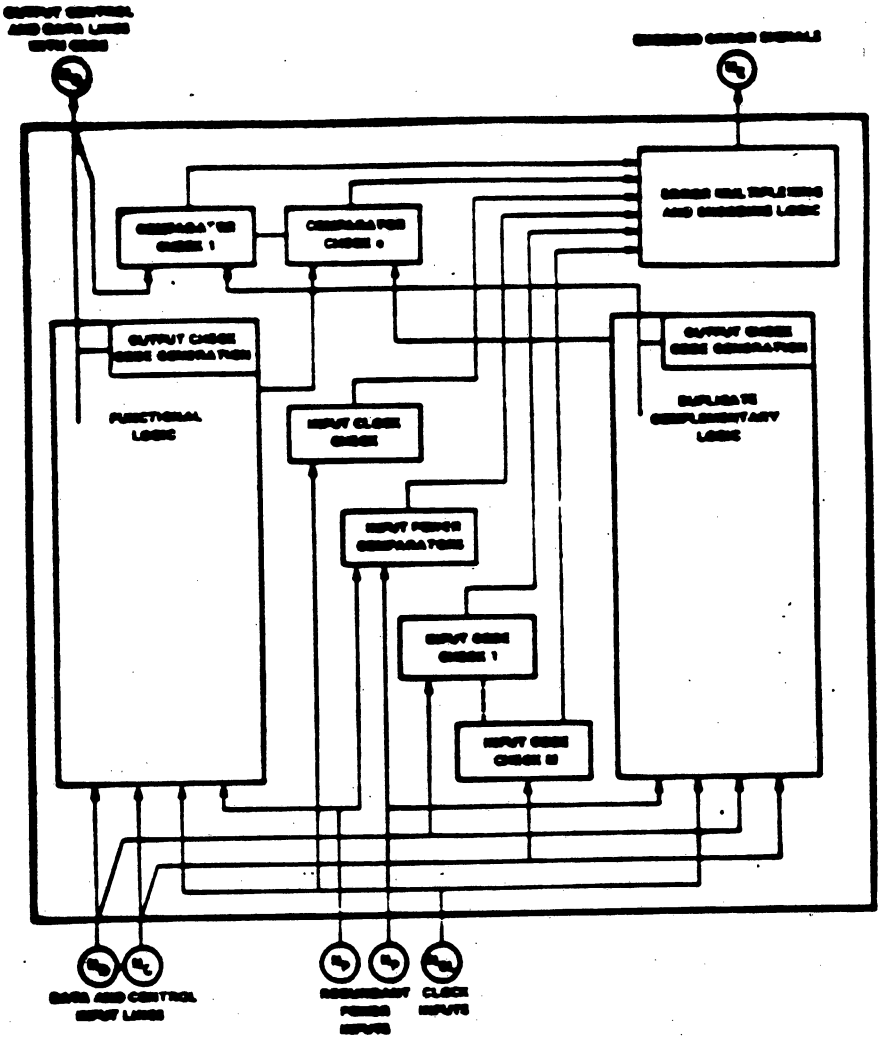


Fig. 1. Generalized VLSI chip.

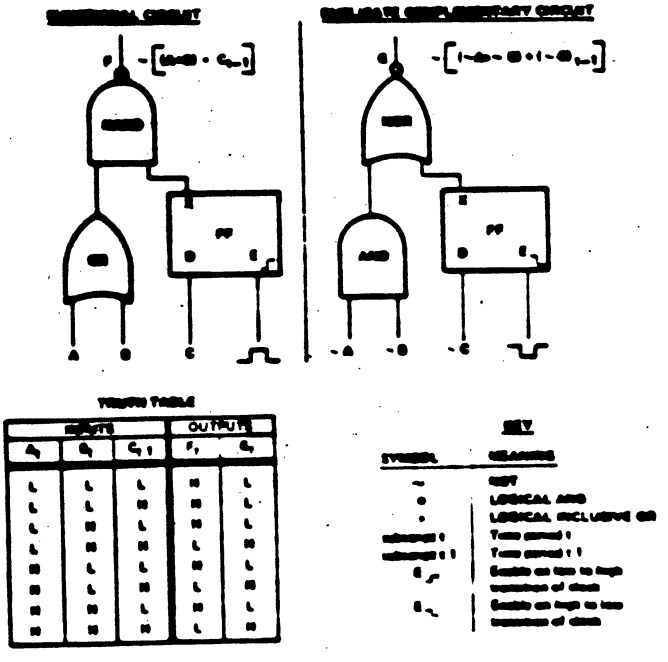


Fig. 2. Example of functional versus duplicate complementary circuits.

Error Correcting Codes

Extra bits not just used to detect, but also to overcome errors

- Triplication could be a code (an expensive one)

Codes -

terminology (n, k) codes

n = length of code word

k = length of actual data

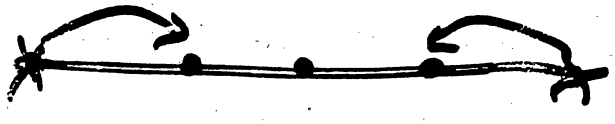
$n-k$ = redundancy

Distance applies here as well

distance-d code can correct up to t errors $\quad d \geq 2t+1$

or detect c errors, correct t' errors, where

$$d \geq 2t' + c + 1$$



$$\underbrace{\begin{matrix} d_1 & d_2 & d_3 & d_4 \end{matrix}}_{\text{Data bits}} \quad \underbrace{\begin{matrix} c_1 & c_2 & c_3 \end{matrix}}_{\text{Check bits}}$$

$$\begin{bmatrix} 1 & 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} d_1 \\ d_2 \\ d_3 \\ d_4 \\ c_1 \\ c_2 \\ c_3 \end{bmatrix} = \text{Syndrome } [S_1 S_2 S_3]$$

Received data word

$$S_1 = d_1 \oplus d_2 \oplus d_3 \oplus c_1$$
$$S_2 = d_1 \oplus d_3 \oplus d_4 \oplus c_2$$
$$S_3 = d_2 \oplus d_3 \oplus d_4 \oplus c_3$$

a. Parity-check matrix and syndrome formation for a (7,4) Hamming SEC code.

	Data bits				Check bits			Syndrome	
Code word (no error)	1	1	1	0	1	0	0	0 0 0	(Zero syndrome implies no error)
One error (box)	1	1	1	[1]	1	0	0	0 1 1	(Matches d_4 column)
Two errors (boxes)	1	[0]	1	0	1	[1]	0	1 1 1	(Matches d_3 column—results in erroneous correction)

b. Received code words and their syndromes for zero, one, and two errors.

c_1	c_2	d_1	c_3	d_2	d_3	d_4
1	0	1	0	1	0	1
0	1	1	0	0	1	1
0	0	0	1	1	1	1

c. Parity-check matrix for (7,4) Hamming code for which syndrome is the binary-coded position of the bit in error.

Figure 3–57. Hamming SEC code examples.

$$\begin{bmatrix} d_1 & d_2 & d_3 & d_4 & c_1 & c_2 & c_3 & c_4 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} d_1 \\ d_2 \\ d_3 \\ d_4 \\ c_1 \\ c_2 \\ c_3 \\ c_4 \end{bmatrix} = [S_1 S_2 S_3 S_4]$$

a. Parity-check matrix for (8,4) Hamming SEC/DED code.

Number of errors	Received data bits				Received check bits				Syndrome			
	d_1	d_2	d_3	d_4	c_1	c_2	c_3	c_4	S_1	S_2	S_3	S_4
Zero	1	1	1	0	0	1	0	0	0	0	0	0
One	1	[0]	1	0	0	1	0	0	1	1	0	1
Two	1	[0]	1	0	0	1	[1]	0	0	1	1	1

b. Received words and their syndromes.

Figure 3–58. Hamming SEC/DED code examples.

Hamming SEC (/DED codes)

↳ $d = 3$ ↳ $d = 4$

correct single bit errors

↓ code word vector

$$\begin{bmatrix} \text{decoding} \\ \text{matrix} \end{bmatrix} \begin{bmatrix} \\ \\ \\ \end{bmatrix} = \begin{bmatrix} \\ \\ \\ \\ \end{bmatrix}$$

↑ Syndrome

$$\begin{array}{c} d_1\ d_2\ d_3\ d_4\ c_1\ c_2\ c_3\ c_4 \\ \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 0 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 1 & 0 & 0 & 0 & 1 \end{bmatrix} \end{array} \cdot \begin{bmatrix} d_1 \\ d_2 \\ d_3 \\ d_4 \\ c_1 \\ c_2 \\ c_3 \\ c_4 \end{bmatrix} = [S_1\ S_2\ S_3\ S_4]$$

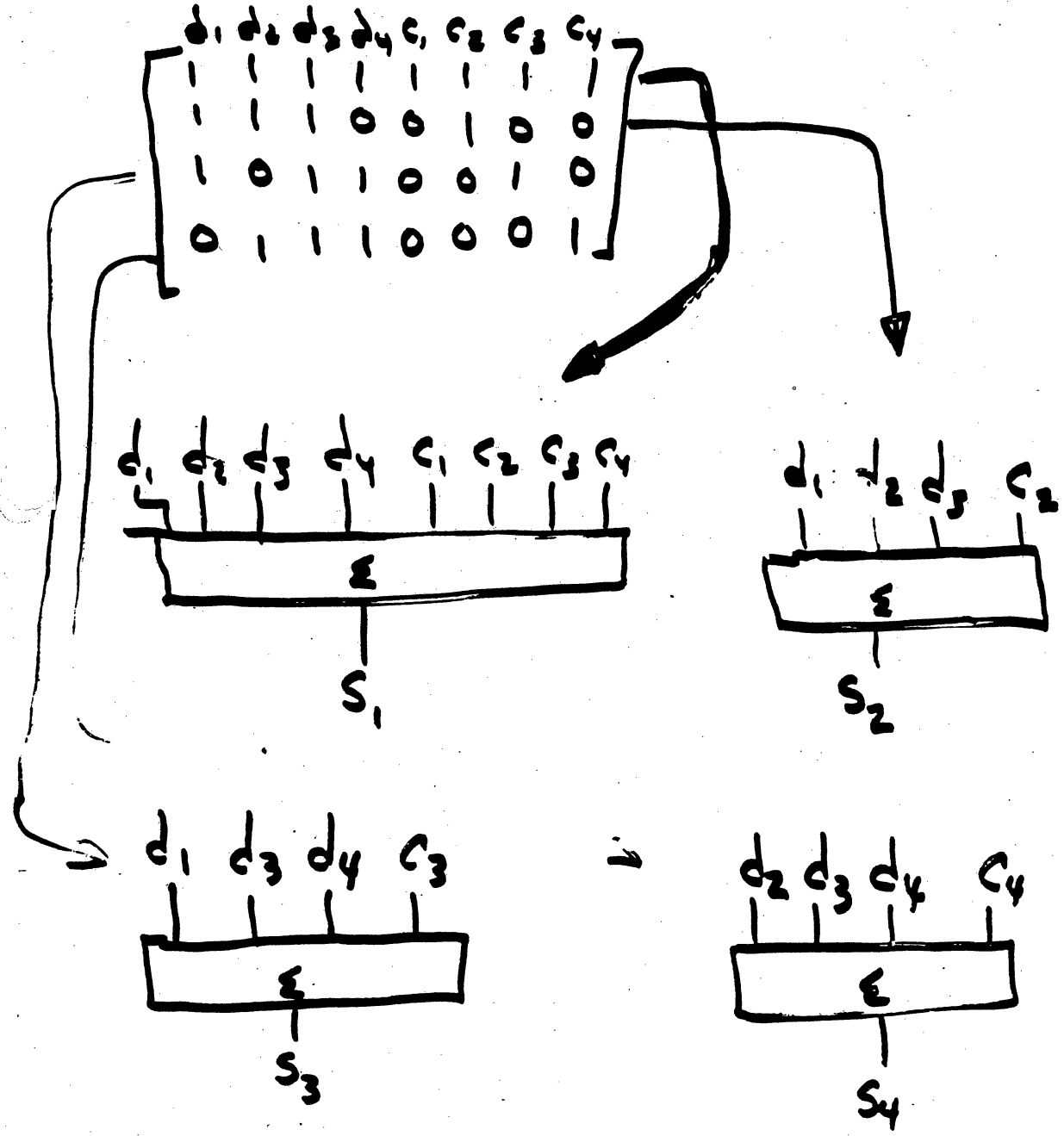
(8,4)-code

even parity

errors	received data bits	received check bits	syndrome
none	1 1 1 0	0 1 0 0	0 0 0 0
one	1 **0** 1 0	0 1 0 0	1 1 **0** 1
two	1 **0** 1 0	0 **1** 1 0	0 1 1 1

Decoding Matrix has a direct implementation in parity trees:

one parity tree to produce each syndrome bit



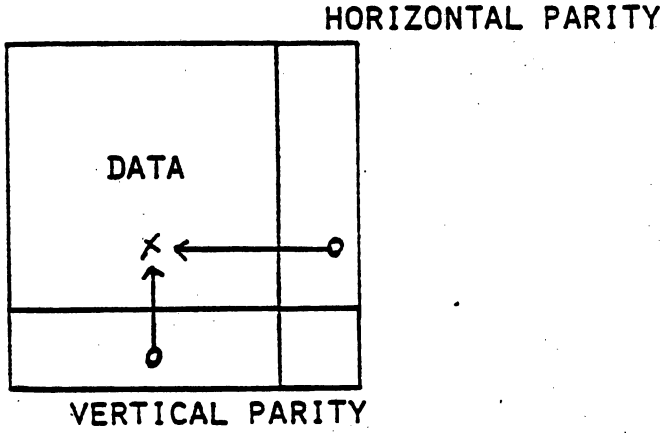
Also: table lookup

ON-LINE CORRECTION

HAMMING CODE

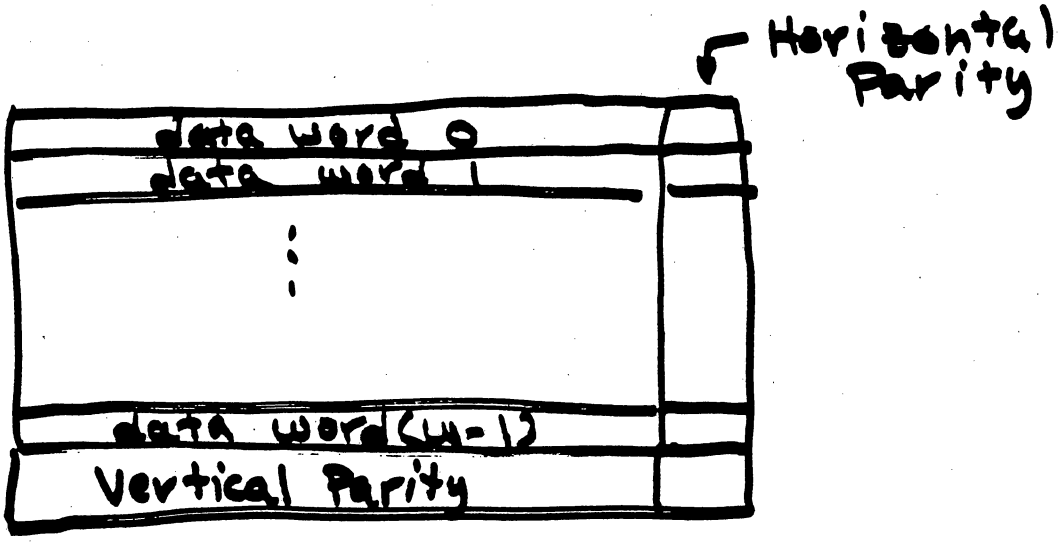
- SEC (BIT)
- SEC/DED (BIT)
- SEC (BIT)/DED (BYTE)
- SEC (BYTE)
- SEC (BYTE)/DED (BYTE)

BLOCK CODE CORRECTION



TRIPLICATION

Block code



special case of a product code

weight (product code)

$$= \prod_{i=1}^{n} \text{weight (code } i\text{)}$$

$d \geq 2t+1$

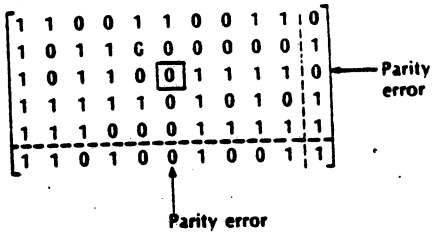


Figure 3–62. Product code using two even-parity codes.

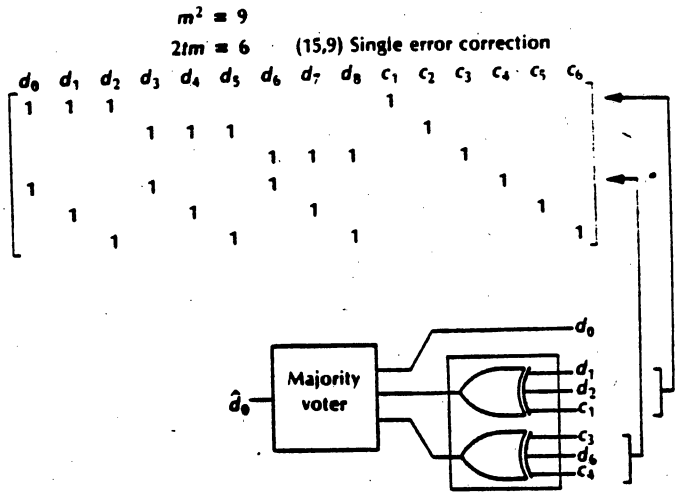
Some other ECC codes

Whole range of cyclic codes
- multiple error
- burst error
- byte error

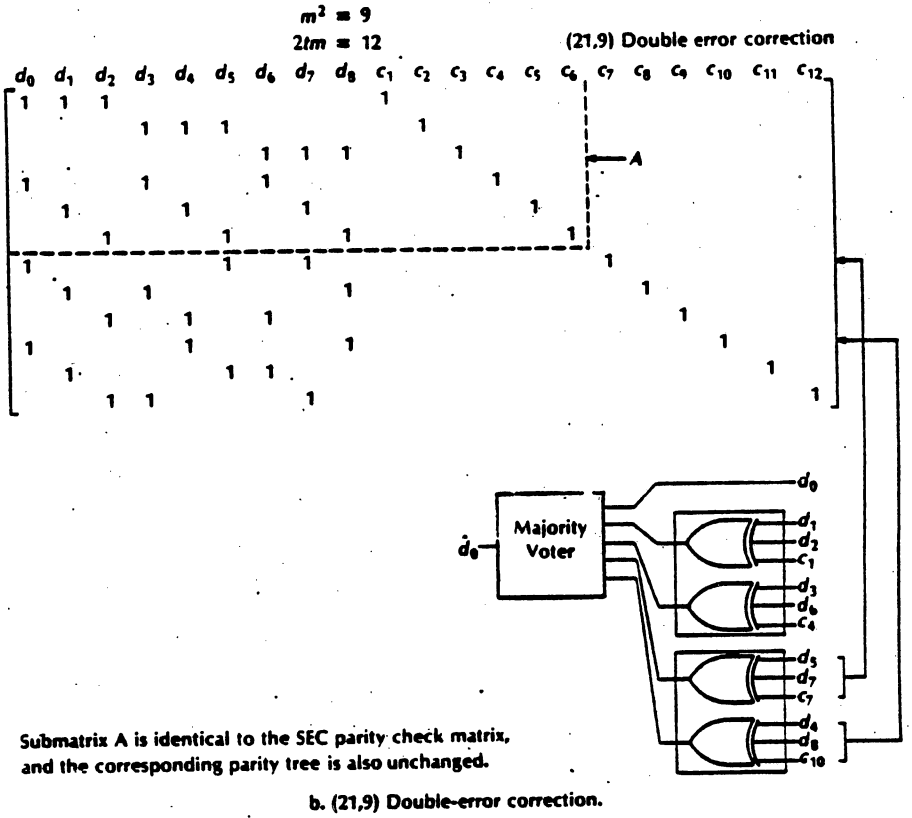
Modified Cyclic codes

The greater the distance, the more complex (expensive, time consuming) the decoding

⇒ more than d=4 extremely rare for ECC codes



a. (15,9) Single-error correction



b. (21,9) Double-error correction.

Figure 3–60. Latin square code parity-check matrix with one bit-slice of decoder for nine data bits. Decoding is performed by a majority vote among the received value of a data bit and two values calculated for it from the other received bits. a.) Single-error correction. b.) Double-error correction.

	Bit planes				
Address	0	1	2	3	Bit location on plane mapped into address SEC code memory
0	0	0	0	0	Initial configuration: two
1	1	1	(1)	[1]	single-bit failures (boxes) and
2	2	2	2	2	a third failure (circle) cause
3	3	3	3	[3]	a double (noncorrectable) error
0	0	(1)	2	[3]	Second configuration:
1	1	0	3	2	with three tolerable
2	2	3	0	[1]	single-bit failures, a fourth,
3	3	2	[1]	0	noncorrectable failure occurs (circle).
0	0	2	3	[1]	Third configuration:
1	1	3	2	0	the fourth failure is
2	2	0	[1]	[3]	no longer aligned with
3	3	(1)	0	2	any other failure; however, another configuration is needed because two old failures are aligned
0	0	3	[1]	2	Fourth configuration:
1	1	2	0	[3]	no double failures
2	2	[1]	3	0	exist, but any additional
3	3	0	2	[1]	failure is unrecoverable.

Figure 3–84. Orthogonal Latin squares–based memory address skewing used to reconfigure a bit-sliced SEC code memory.

	Bit planes				
Address	0	1	2	3	Bit location on plane mapped into address SEC code memory
0	0	0	0	0	Initial configuration: two
1	1	1	(1)	[1]	single-bit failures (boxes) and
2	2	2	2	2	a third failure (circle) cause
3	3	3	3	[3]	a double (noncorrectable) error
0	0	(1)	2	[3]	Second configuration:
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1	1	3	2	0	the fourth failure is
2	2	0	[1]	[3]	no longer aligned with
3	3	(1)	0	2	any other failure; however, another configuration is needed because two old failures are aligned.
0	0	3	[1]	2	Fourth configuration:
1	1	2	0	[3]	no double failures
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3	3	0	2	[1]	failure is unrecoverable.

Figure 3–84. Orthogonal Latin squares–based memory address skewing used to reconfigure a bit-sliced SEC code memory.

Table 3–13. Single-error-correcting AN codes.

Check Modulus A	*Maximum Data Length k*	*Code Word Length n*
13	2	6
19	4	9
23	6	11
29	9	14
37	12	18
47	17	23
53	20	26
59	23	29
61	24	30
67	26	33
71	28	35
79	32	39
83	34	41
101	42	50
103	43	51

Source: Kautz [1962]

Reconfiguration

- Based upon error detection
- coverage important factor in modelling
- rollback strategies -
  process recovery after reconfiguration
  - state checkpointing

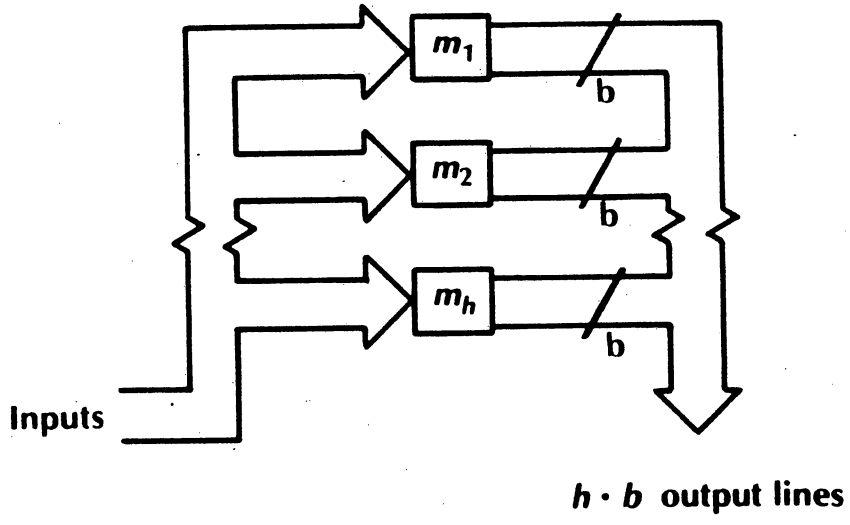
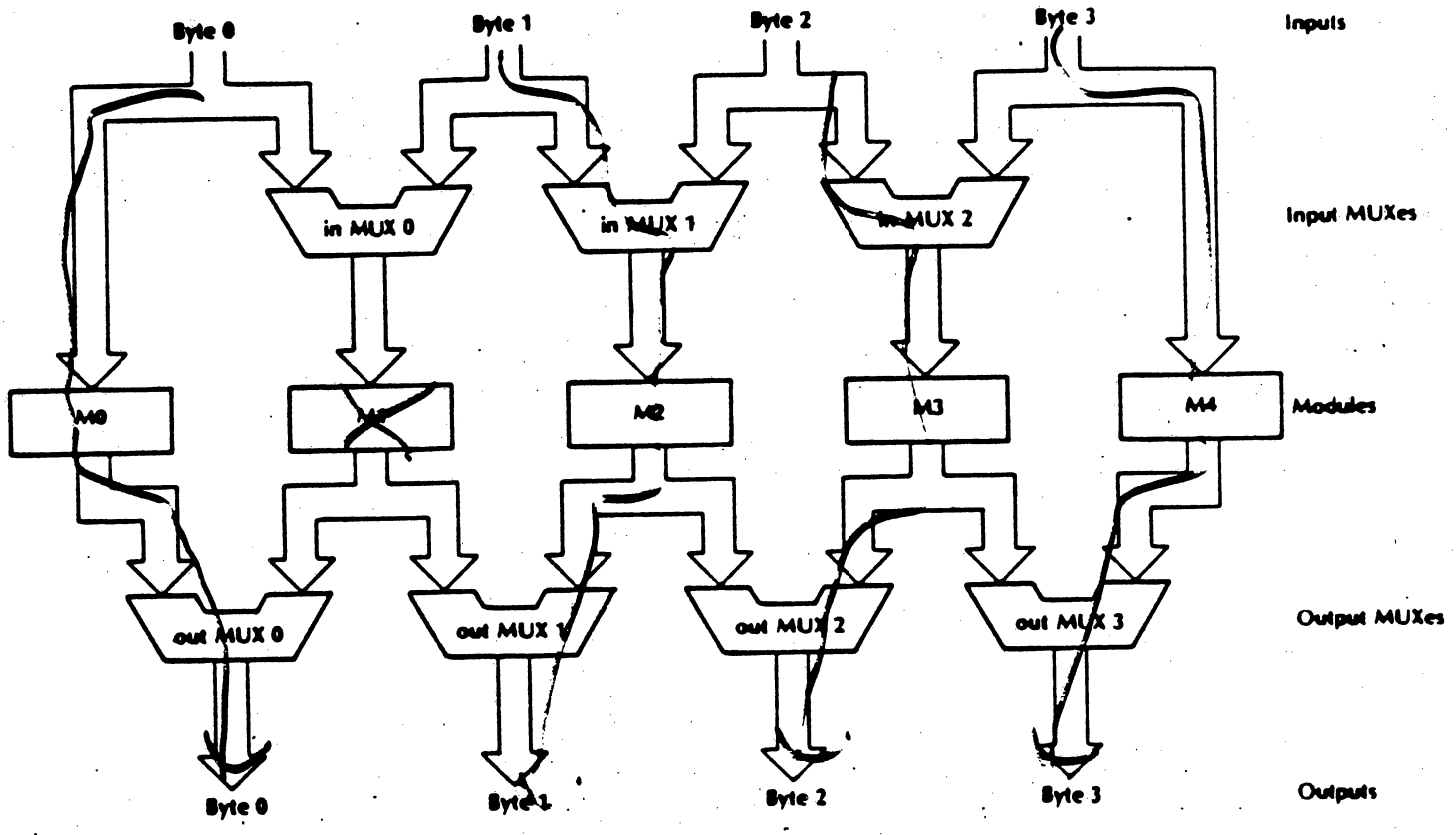


Figure 3–59. Circuit design of parallel byte-wide modules.



Control input to MUX: 0 (left leg), 1 (right leg)

Normal control line state: (in MUX 0, in MUX 1, in MUX 2) = (1, 1, 1)
(out MUX 0, out MUX 1, out MUX 2, out MUX 3) = (0, 0, 0, 0)

Control line state if M2 failed: in MUX = (1,X,0)
out MUX = (0,0,1,1)
X = don't care

Figure 3-19. Possible implementation of a system made from four byte slice... added as a spare.

ARANTEED

Evaluation Criteria

1. What are some good measures of "reliability"?

2. How can we model systems to evaluate their potential "reliability"?

Deterministic Model

System must tolerate k failures. (k = figure of merit)

=> potentially wasteful allocation of resources--some components have much higher failure rates than others

Probabilistic Models

- based on component failure distributions
- several levels of detail
  - chip (gate, component) level
  - module level (often nonredundant)
  - system level

Redundant System Models

The form of the model depends upon the assumptions made:

- failure to exhaustion of spares

  => combinatorial model

- failure with repair

  => Markov model

- failure with periodic maintenance

  => Markov model

Evaluation Criteria

Probabilistic Functions

- Reliability $R(t)$
- Mission Time $MT(r)$

Single Parameters (Probabilistic)

- Mean Time To Failure (MTTF)

Comparative Measures (Probabilistic)

- Reliability Difference $R_2(t) - R_1(t)$
- Unreliability Gain $\frac{1 - R_2(t)}{1 - R_1(t)}$
- Mission Time Improvement $\frac{MT_2(r)}{MT_1(r)}$

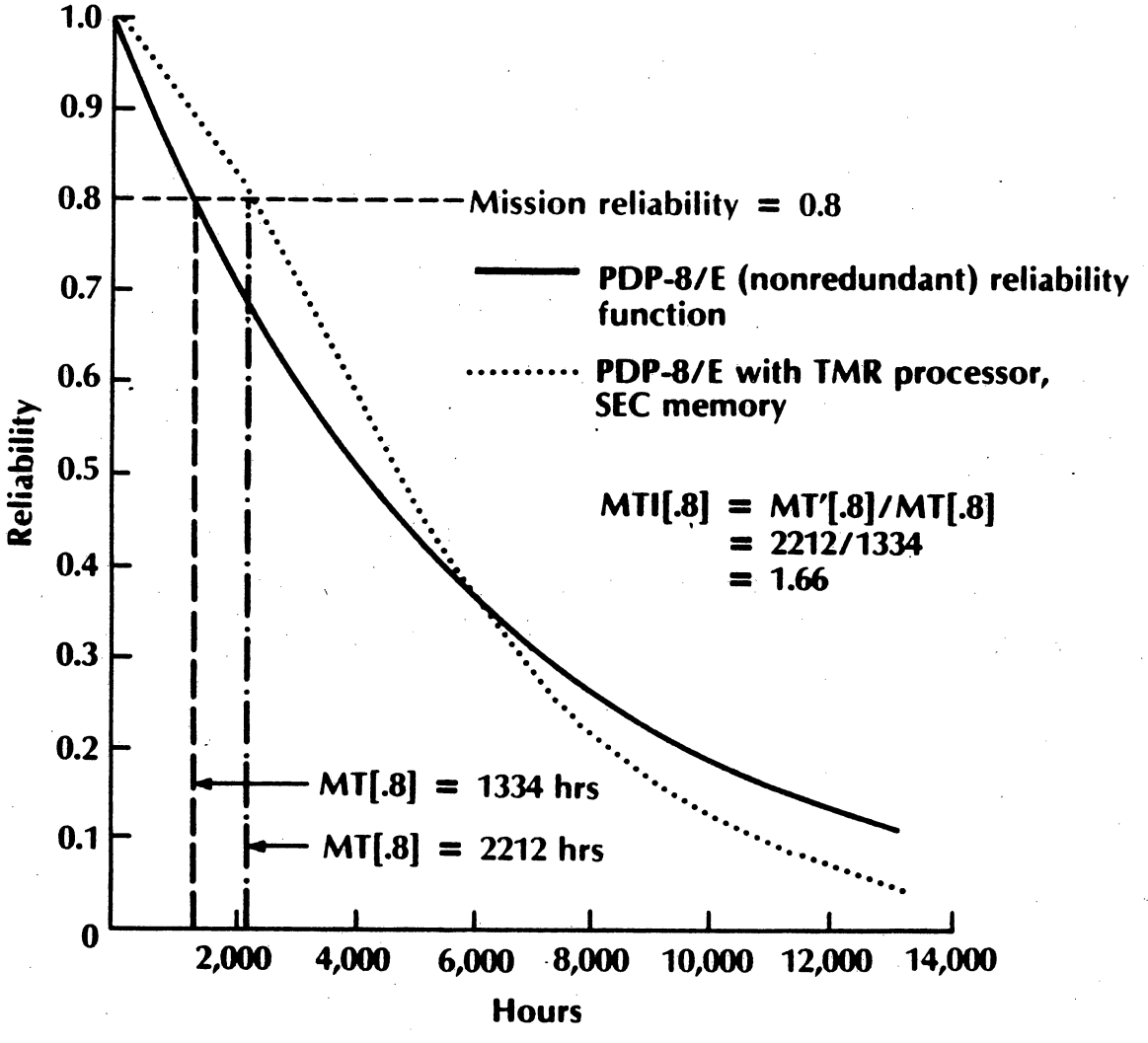
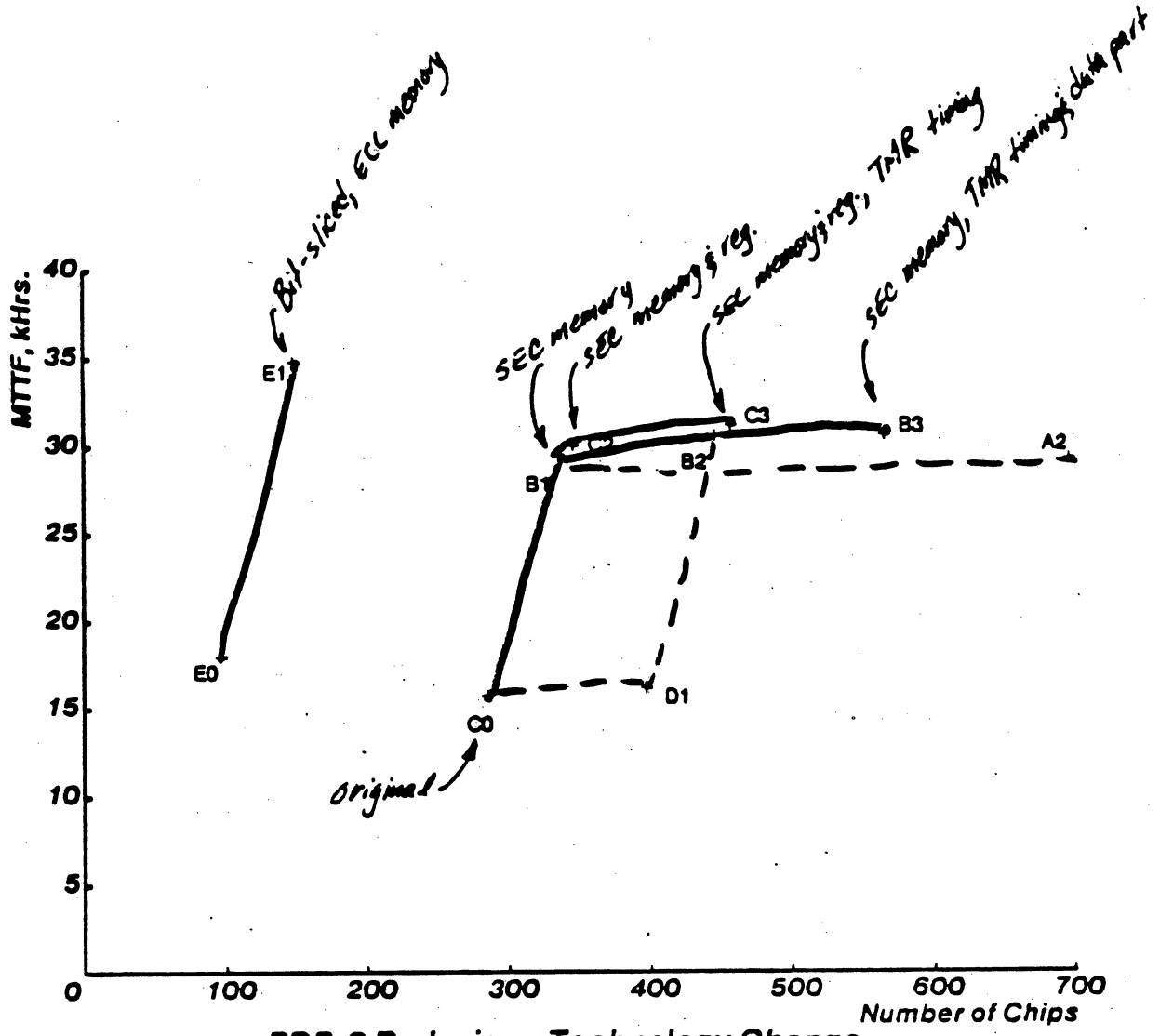
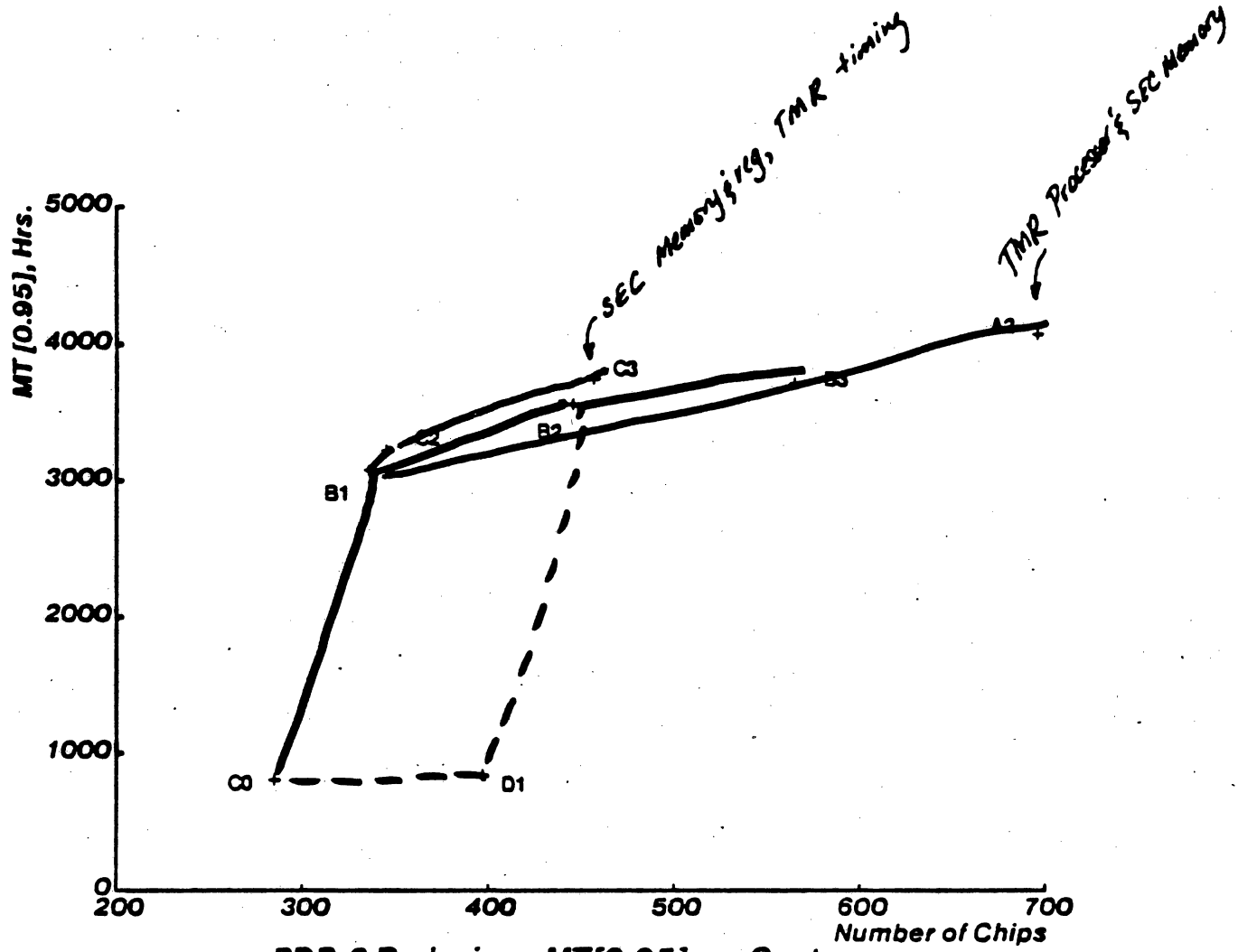


Figure 5–6. Relation of reliability function, mission time, and mission reliability.

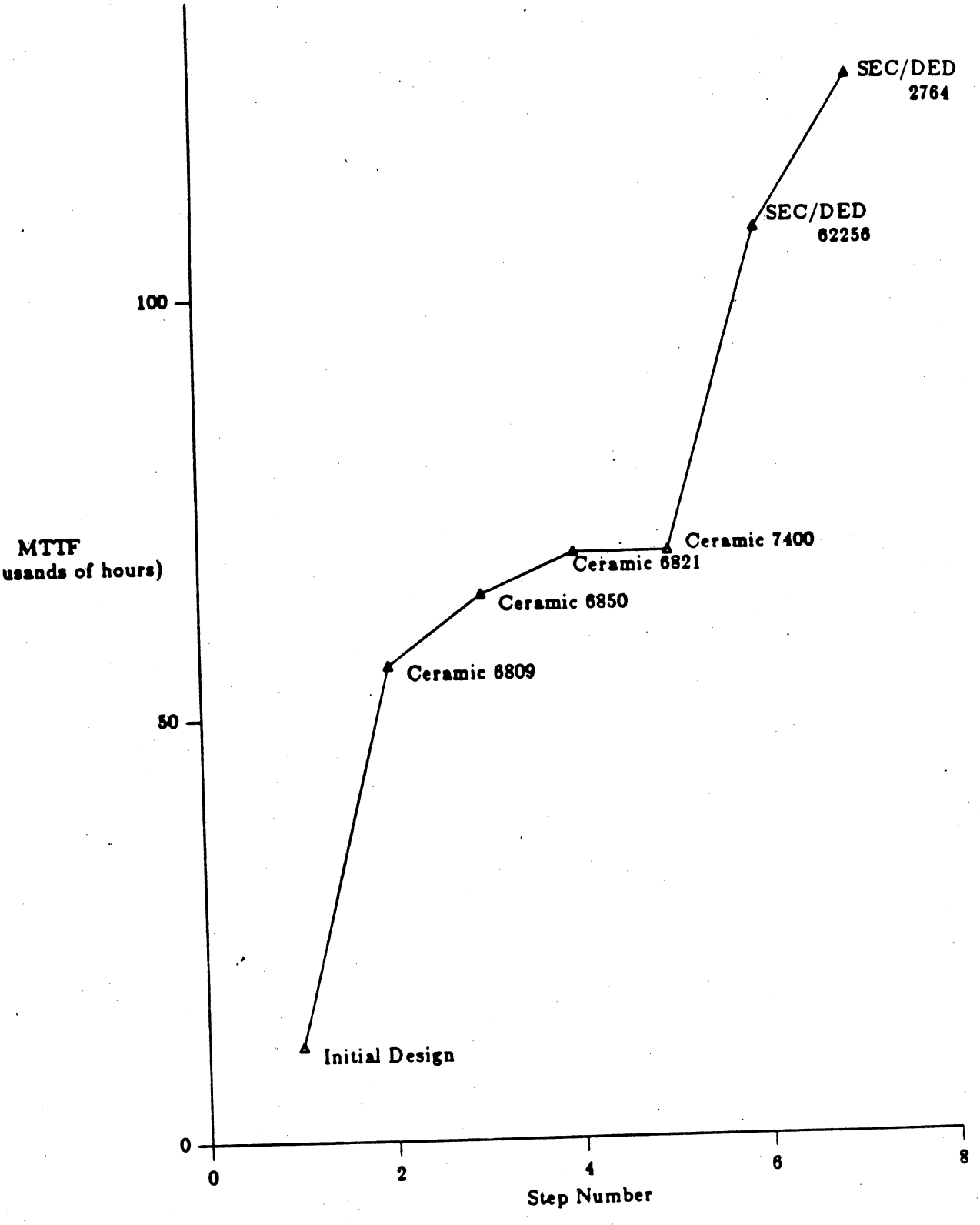


PDP-8 Redesign - Technology Change



PDP-8 Redesign - MT[0.95] vs. Cost

Results of Fault Tolerant Design

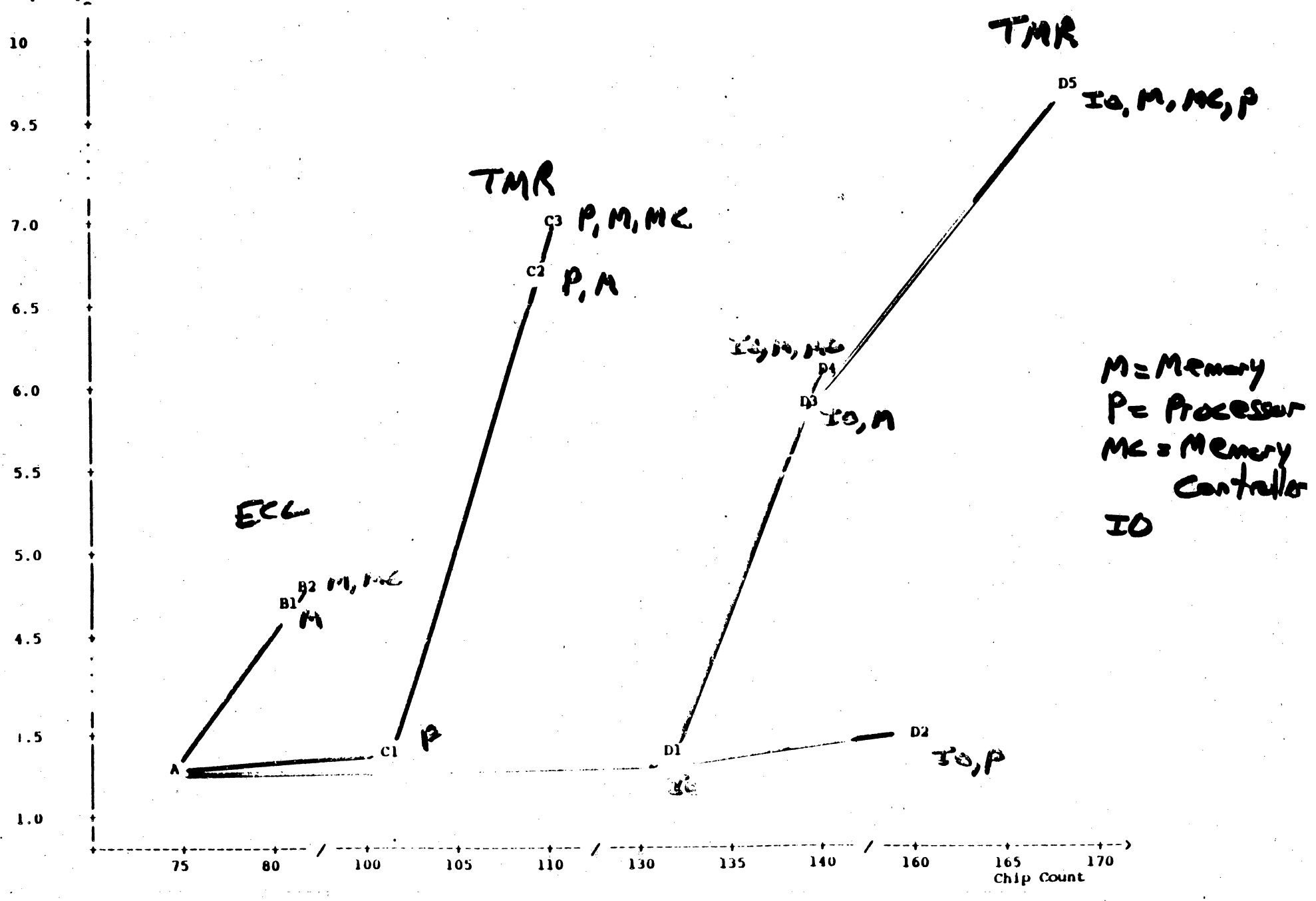


Summary of Results for the 6809 Singleboard Computer Redesign Project

Module Name				Output	Design	MTTF	MT[0.95]	Chip
I/O I-Face	Processor	Main Memory	Memory Control	Filename	Label	(in thousands of hrs)		Count
O	O	O	O	BASECASE	A	25.468	1.309	74
O	O	R	O	ECC	B1	91.01	4.678	81
O	O	R	R	ECC	B2	93.99	4.834	82
O	R	O	O	TMR	C1	26.62	1.436	102
O	R	R	O	TMR	C2	89.57	6.660	109
O	R	R	R	TMR	C3	92.06	6.953	110
R	O	O	O	TMRIO	D1	26.83	1.389	132
R	R	O	O	TMRIO	D2	28.06	1.533	160
R	O	R	O	TMRIO	D3	104.4	5.889	139
R	O	R	R	TMRIO	D4	108.1	6.133	140
R	R	R	R	TMRIO	D5	104.8	9.707	168

KEY:
O ==> Original (non-redundant) Configuration
R ==> Redundant Configuration

Design-Space Graph for the 6809 Redesign Problem -- MT[0.95] -vs- Chip Count



Reliability Evaluation:
Reliability Measures

- Reliability function (R(t))
- Hazard function (z(t))
- "Mean time" measures (MTTF, MTBF, MTTC, MTBC)
- Mission measures ($\dot{M}T(r)$, MR(t), MTI(r))
- Repairability (MTTR, diagnosability)
- Availability (A(t), A)
- Coverage (fault detection and recovery)
- Cost (LCC, BMC)
- Performance (MCBF, $E[t_{complete}]$, performability)

Fault Handling Techniques and Their Evaluation

DESIGN FOR SYSTEM RELIABILITY

6 Fault Handling Techniques

OBJECTIVES

* A survey of fault handling techniques
* The stages in fault handling

Reliability bottleneck: (present in all schemes using redundancy)

Classic dilemma: who shall guard the guardians?

Single points of failure

in duplication, the comparison elements

can use redundancy to further reduce single points of failure; but there is a decreasing return for incremental changes

- avoid overconcern about single points of failure: too much redundancy could be less reliable.

Another problem

Synchronization

→ cause of failure

→ cause of perf. degr.

→ solution often taken (common clock) creates single point of failure)

Common to most replication techniques

Detection using redundancy to detect failure occurrence, preferably before error propagates

Fail-Safe if failure occurs, output is in "safe" position
e.g. bomb fuze
traffic light

Fault-Secure output can be wrong, but it must be accompanied by error signal if it is.

Table 3–14. Critical and subcritical input faults for some common logic gates.

Gate Type	*Critical Faults*	*Subcritical Faults*
AND	$1 \rightarrow 0$	$0 \rightarrow 1$
OR	$0 \rightarrow 1$	$1 \rightarrow 0$
NOT	$0 \rightarrow 1$, $1 \rightarrow 0$	None
NAND	$1 \rightarrow 0$	$0 \rightarrow 1$
Majority	None	$0 \rightarrow 1$, $1 \rightarrow 0$

Fail-Safe & Fault-Secure Logic

Definitions:

Self-checking circuit is one whose outputs are coded in an error code.

Self-testing circuit is one for which, for every fault f from a specific set of faults F, the circuit produces a non code space output for at least one code space input.

Fault-secure circuit is ckt which for every fault $f \in F$ produces either a non code space output or the correct code space output for all code space inputs.

also Totally & Partially self-checking ckts

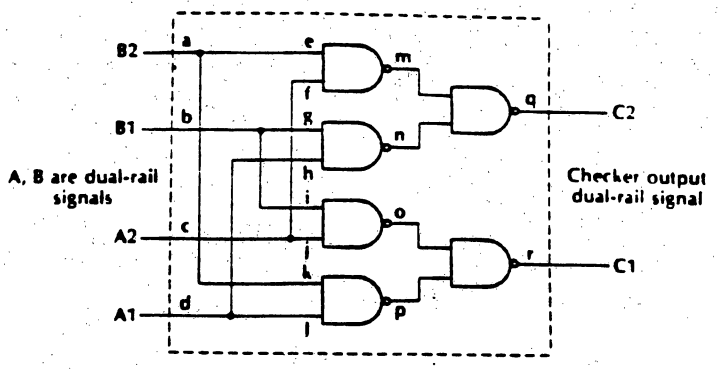


Figure 3–36. Logic circuit of basic TSC comparison element.

Table 3–12. TSC dual-rail comparator responses to stuck-at-faults.

Inputs		*Normal*	*Outputs C2C1 Resulting from Single Stuck-at-1 Faults*																	
B2B1	*A2A1*	*Output*	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*	*n*	*o*	*p*	*q*	*r*
01	01	10	11	10	11	10	10	10	10	10	10	11	11	10	10	00	10	10	10	11
01	10	01	11	01	01	11	11	01	01	11	01	01	01	01	01	01	00	01	11	01
10	01	01	01	11	11	01	01	11	11	01	01	01	01	01	01	01	01	00	11	01
10	10	10	10	11	10	11	10	10	10	10	11	10	10	11	00	10	10	10	10	11
Inputs		*Normal*	*Outputs C2C1 Resulting from Single Stuck-at-0 Faults*																	
B2B1	*A2A1*	*Output*	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*	*n*	*o*	*p*	*q*	*r*
01	01	10	10	00	10	00	10	10	00	00	10	10	10	10	10	10	11	11	00	10
01	10	01	01	00	00	01	01	01	01	01	00	00	01	01	11	11	01	01	01	00
10	01	01	00	01	01	00	01	01	01	01	01	01	00	00	11	11	01	01	01	00
10	10	10	00	10	00	10	00	00	10	10	10	10	10	10	10	10	11	11	00	10

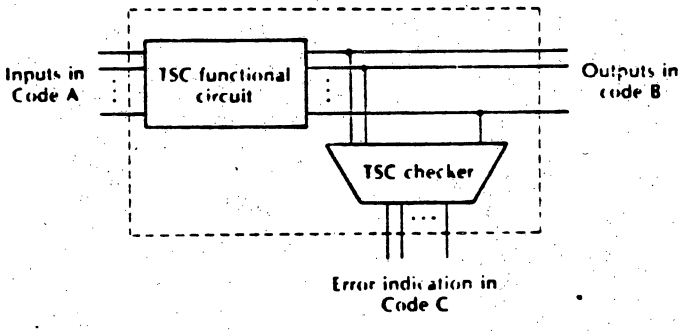


Figure 3–37. A TSC network made from TSC elements

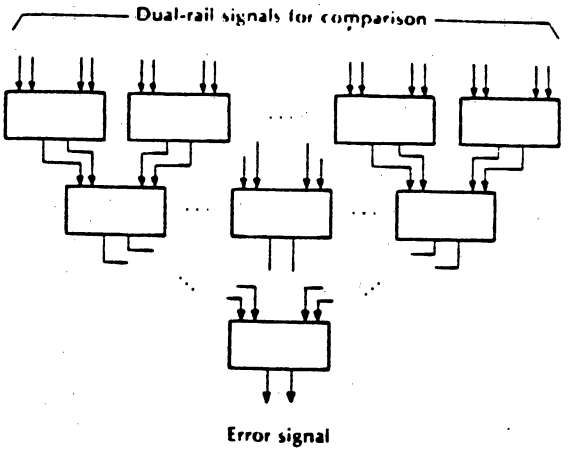


Figure 3–38. Assembly of *n*-input dual-rail signal comparison checker from basic two-input elements.

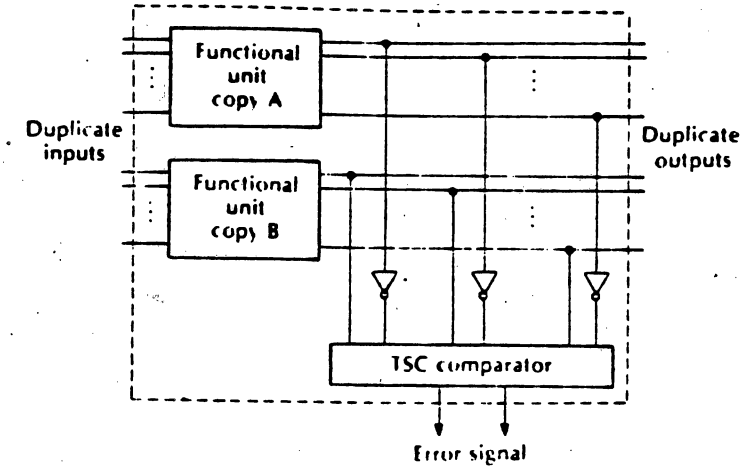


Figure 3–39. TSC network based on duplication as a code.

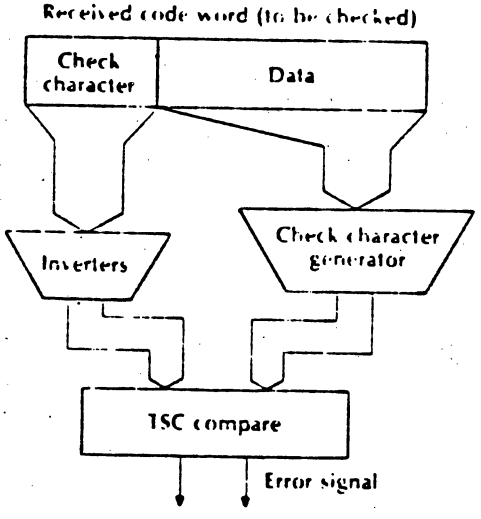


Figure 3–40. TSC detector for separable cou based on a TSC comparator.

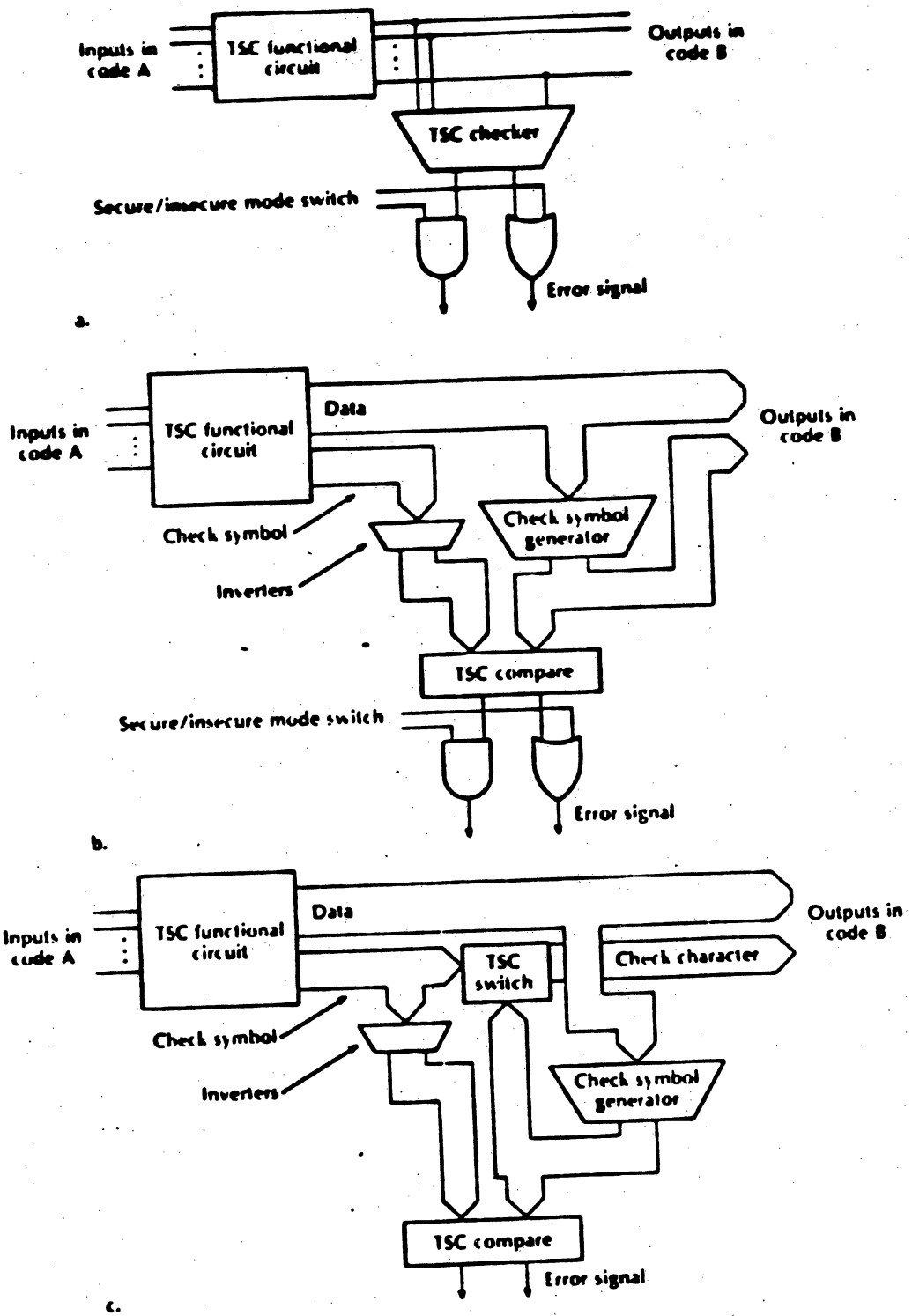


Figure 3–41. Types of PSC networks. a.) Type 1. b.) Type 2 c.) Type 3.

FAULT TOLERANCE

Goal:
To actually withstand (tolerate) faults, and continue operation.

Static
Dynamic } Redundancy

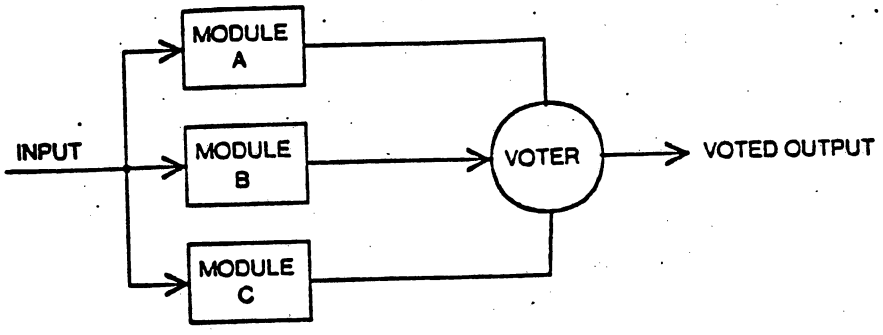


Figure <tmr basic> Basic Triple Moodular Redundancy. Modules A, B, and C are functionally identical.

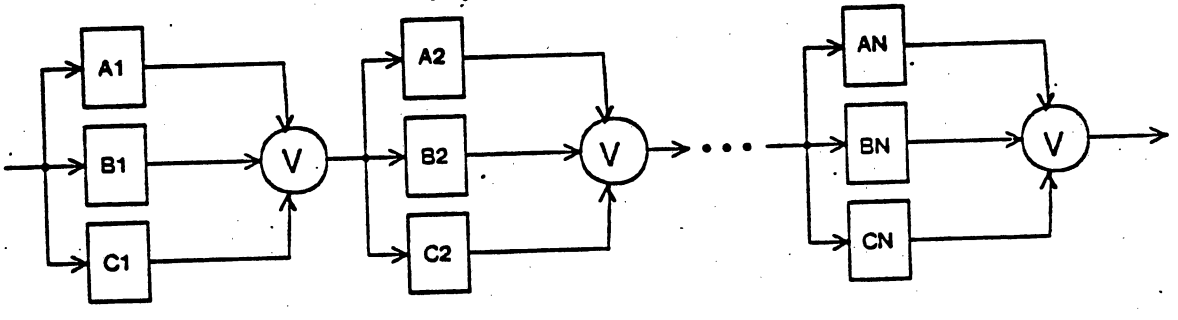


Figure <TMR cascade> Cascading of TMR modules.

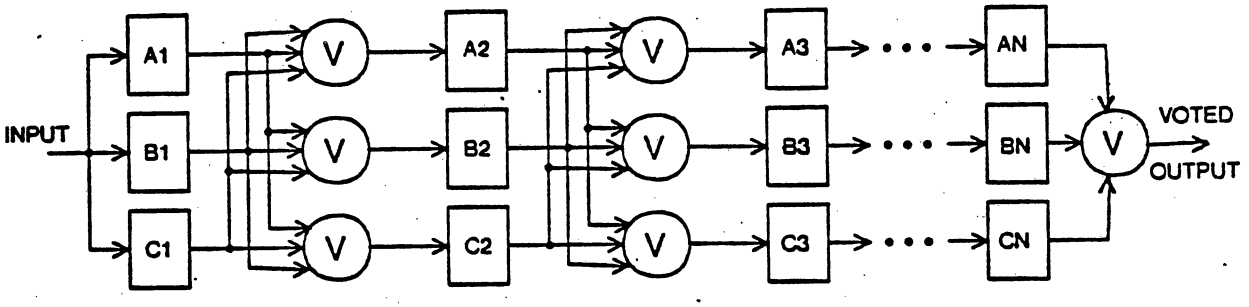


Figure <TMR voters> TMR voters remove almost all single points of failure (except the final output voter).

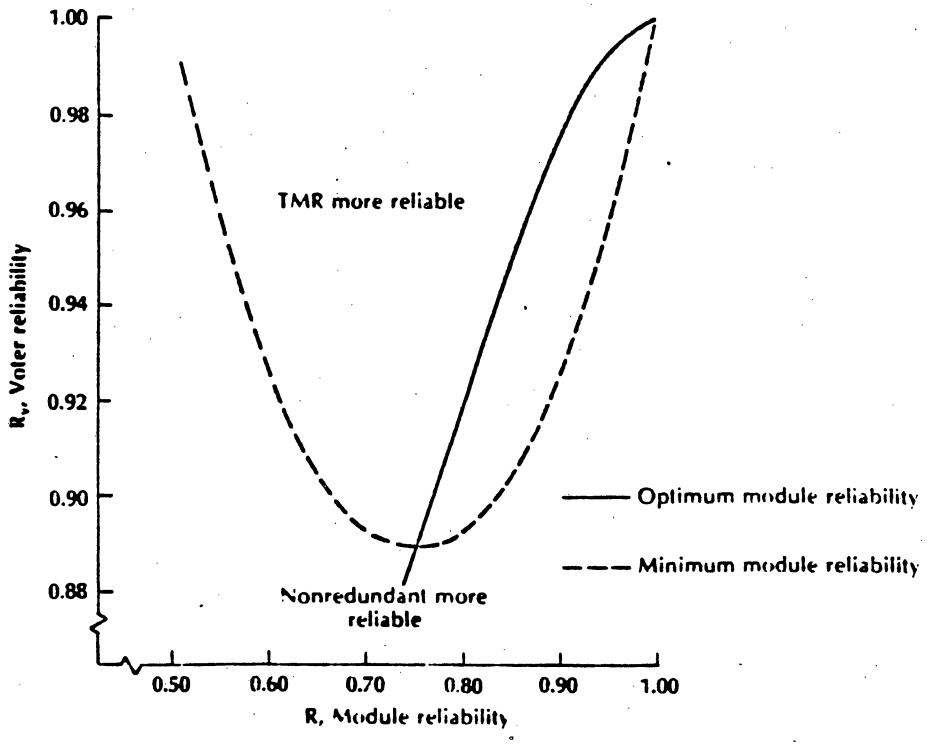


Figure 3–47. Decision regions for single voter TMR. (© 1965 IEEE.)

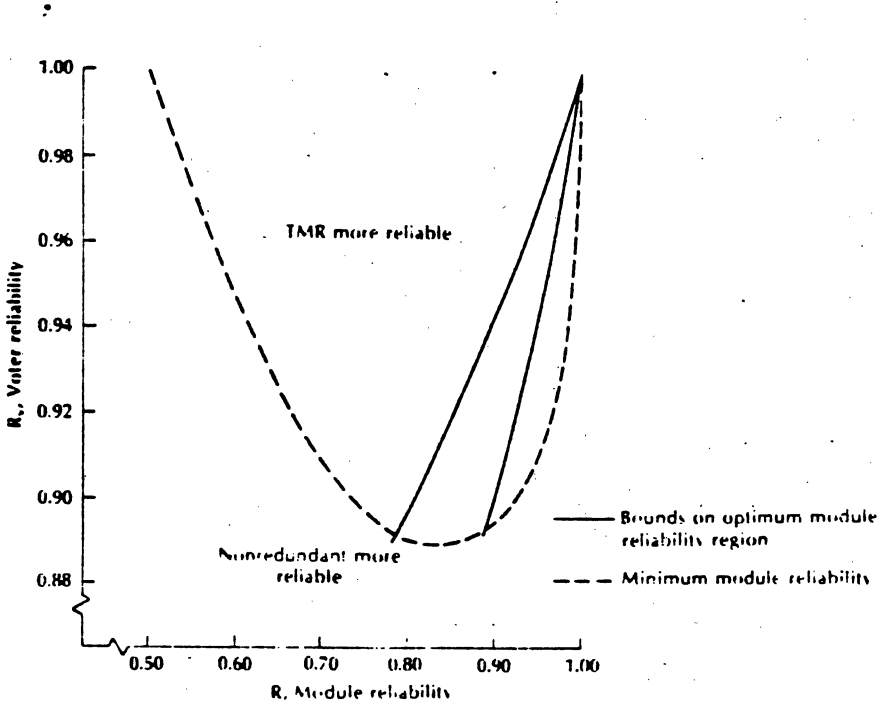
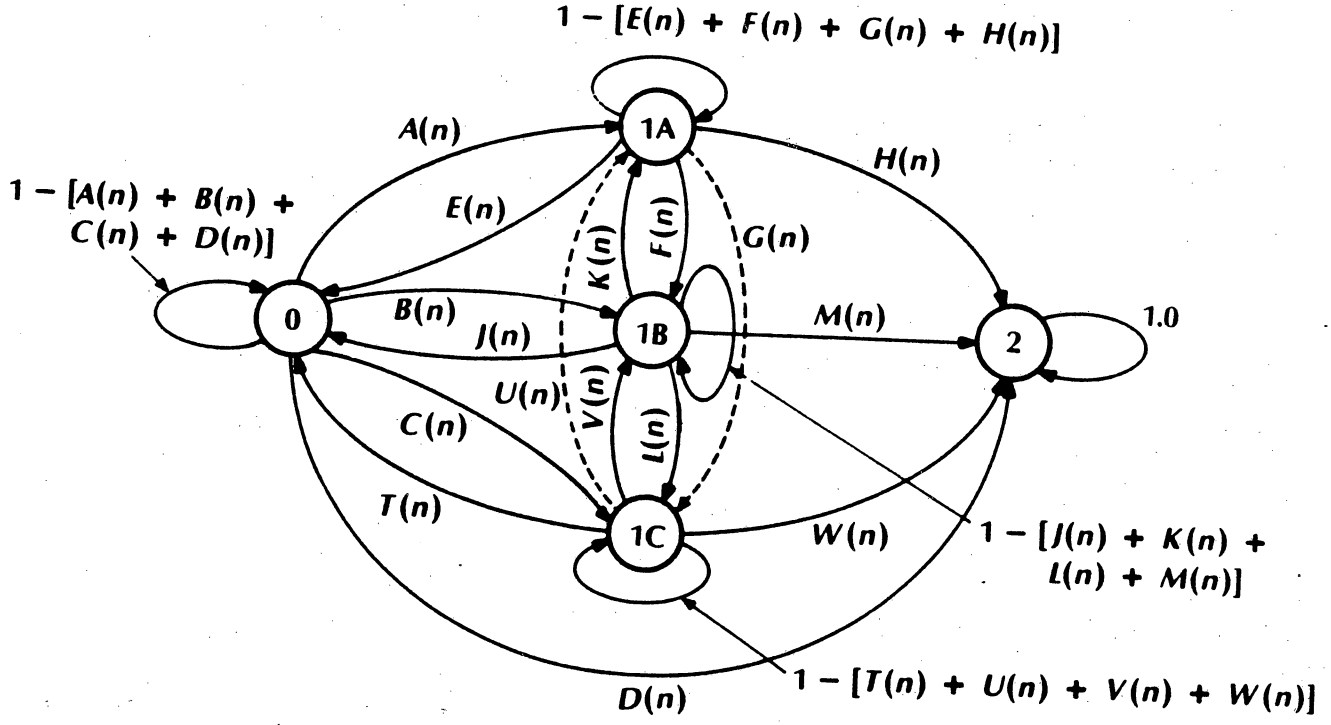


Figure 3–48. Decision regions for triplicated voter TMR. (© 1965 IEEE.)



$$A(n) = Z_f(n - N_A)[1 - Z_f(n - N_B)][1 - Z_f(n - N_C)]$$

$$B(n) = [1 - Z_f(n - N_A)]Z_f(n - N_B)[1 - Z_f(n - N_C)]$$

$$C(n) = [1 - Z_f(n - N_A)][1 - Z_f(n - N_B)]Z_f(n - N_C)$$

$$D(n) = Z_f(n - N_A)Z_f(n - N_B)[1 - Z_f(n - N_C)] + Z_f(n - N_A)[1 - Z_f(n - N_B)]Z_f(n - N_C) + \cdots$$

$$E(n) = \cdots$$

$$Z_f(n) = q_f^{(n+1)^\alpha - n^\alpha}; \quad q_f = e^{-(\lambda \Delta t)^\alpha}$$

$$Z_r(n) = q_r^{(n+1)^\beta - n^\beta}; \quad q_r = e^{-(\mu \Delta t)^\beta}$$

N_A = Time of last transition from state 1A to state 0

Figure 5–49. TMR model with failure process renewals.

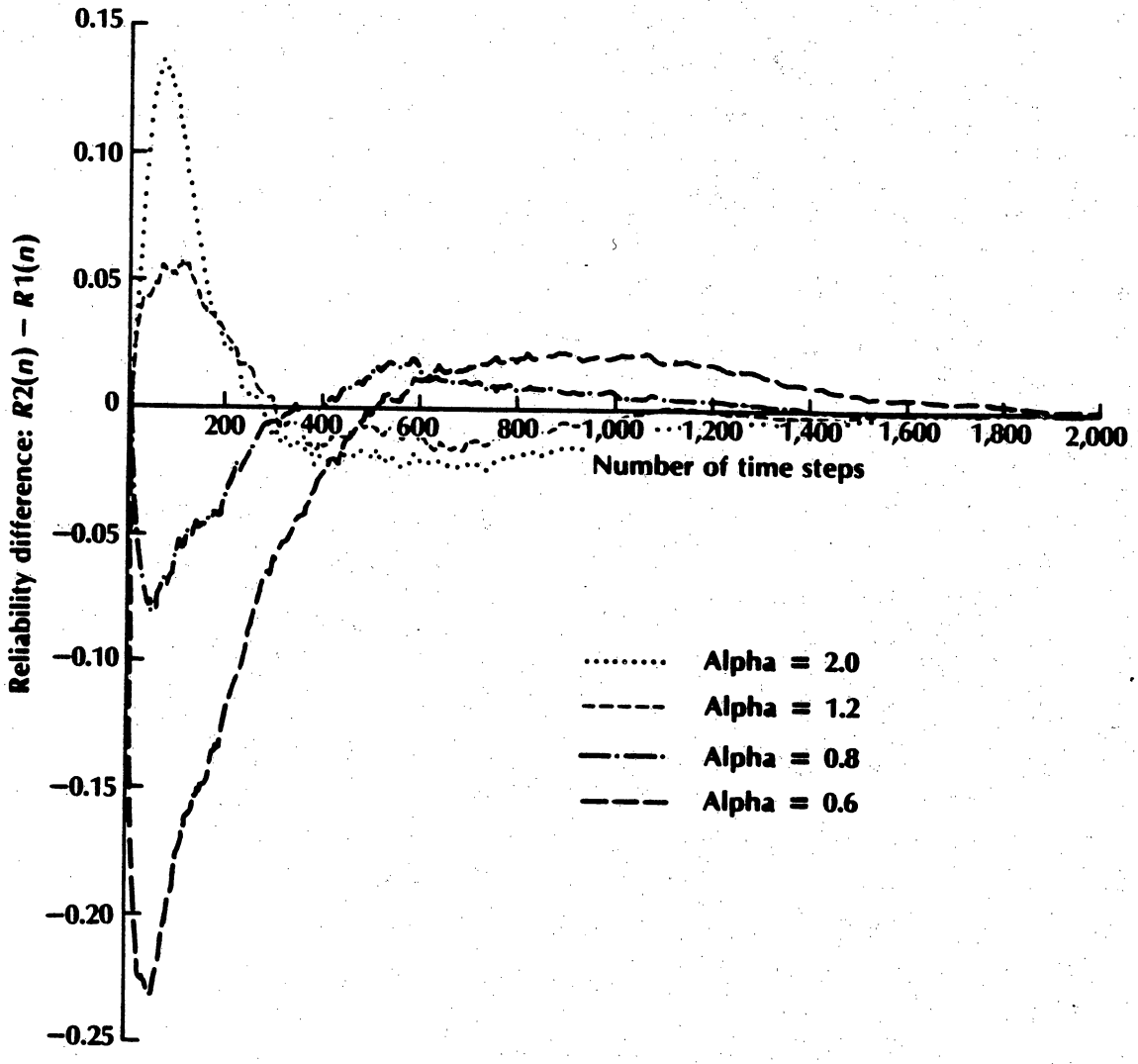


Figure 5–51. Reliability differences for simulated TMR system.

Combinatorial Model

For a system with N identical modules, K of which are necessary for operation

$$R_{sys}(t) = \sum_{i=0}^{N-k} \binom{N}{i} \left(R_m(t)\right)^{N-i} \left[1 - R_m(t)\right]^i$$

EXAMPLE: TMR system

3 modules, need 2

$$R_{TMR} = \sum_{i=0}^{1} \binom{3}{i} R_m^{3-i} (1-R_m)^i$$

$$= \binom{3}{0} R_m^3 + \binom{3}{1} R_m^3 (1-R_m)$$

$$= R_m^3 + 3R_m^2 (1-R_m)$$

$$= R_m^3 + 3R_m^2 - 3R_m^3$$

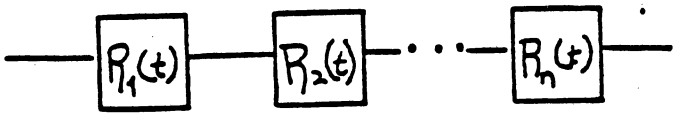
$$R_{TMR} = 3R_m^2 - 2R_m^3$$

which is a very well known formula

$$R_{TMR} = 3e^{-2\lambda t} - 2e^{-3\lambda t}$$

$$\neq K_2 e^{-K_1 t}$$

SERIES/PARALLEL REDUNDANCY



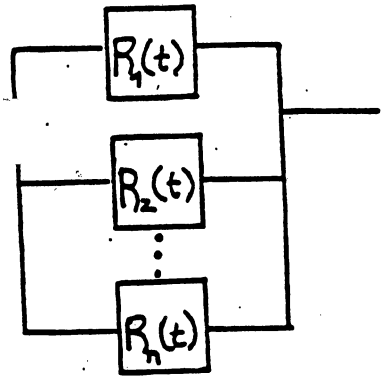
series connection

series reliability unreliability

$$R_{series}(t) = \prod_{i=1}^{n} R_i(t)$$

where $Q_i = 1 - R_i$

$$Q_{series}(t) = 1 - \prod_{i=1}^{n} (1 - Q_i(t))$$



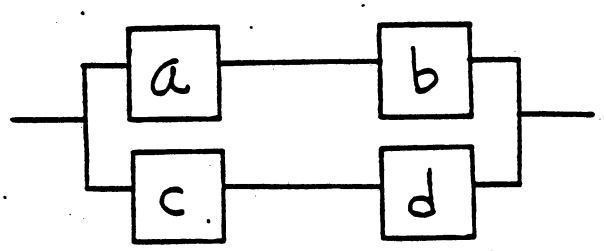
parallel connection

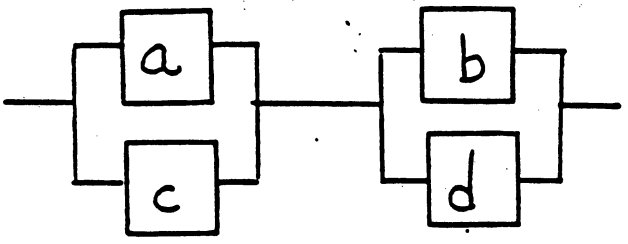
parallel reliability unreliability

$$R_{parallel}(t) = 1 - \prod_{i=1}^{n} (1 - R_i(t))$$

$$Q_{parallel}(t) = \prod_{i=1}^{n} Q_i(t)$$

SERIES/PARALLEL EXAMPLE

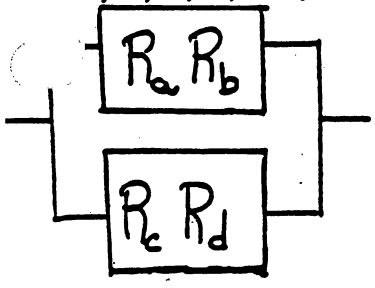




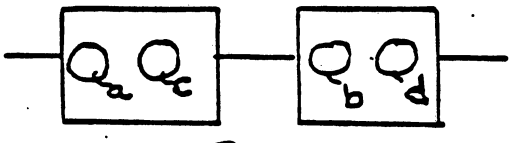
working path includes at least 1 good unit

shorts tolerated
a,b,c,d,ac,ad,bc,bd
opens tolerated
a,b,c,d,ab,cd

shorts tolerated
a,b,c,d,ac,bd
opens tolerated
a,b,c,d,ab,ad,cb,cd



R_{short}



R_{open}

$$R_{short} = 1 - (1-R_aR_b)(1-R_cR_d)$$
$$= R_aR_b + R_cR_d - R_aR_bR_cR_d$$

$$R_{open} = (1 - (1-R_a)(1-R_c))(1 - (1-R_b)(1-R_d))$$
$$= R_aR_b + R_bR_c + R_cR_d + R_aR_d$$
$$+ R_aR_bR_cR_d - R_aR_bR_c$$
$$- R_aR_bR_d - R_aR_cR_d - R_bR_cR_d$$

SERIES/PARALLEL EXAMPLE (cont.)

simplification #1

$$R_a = R_c = R_p,\ R_b = R_d = R_m$$

$$R_{short} = 2R_pR_m \cdot (R_pR_m)^2$$

$$R_{open} = (R_p + R_m)^2 + (R_pR_m)^2 \cdot 2R_pR_m(R_p + R_m)$$

simplification #2

$$R_a = R_b = R_c = R_d = R$$

$$R_{short} = 2R^2 \cdot R^4$$

$$R_{open} = 4R^2 \cdot 4R^3 + R^4$$

NOTE:

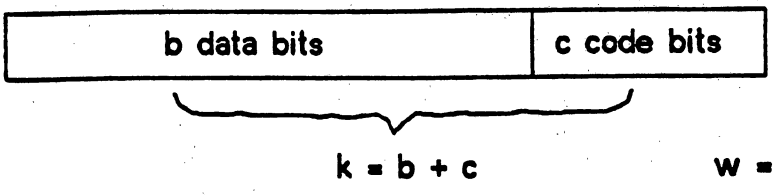
$$R_{open} > R_{short}$$

for $0 < t < \infty$

TWO ALTERNATIVES FOR ECC

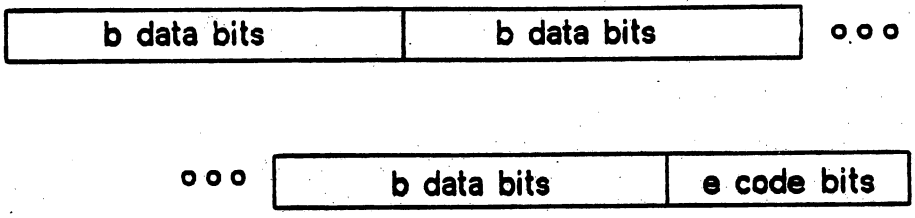
1. Hamming code

a)



SINGLE LOGICAL WORD PER PHYSICAL WORD

b)



j LOGICAL WORDS PER PHYSICAL WORD

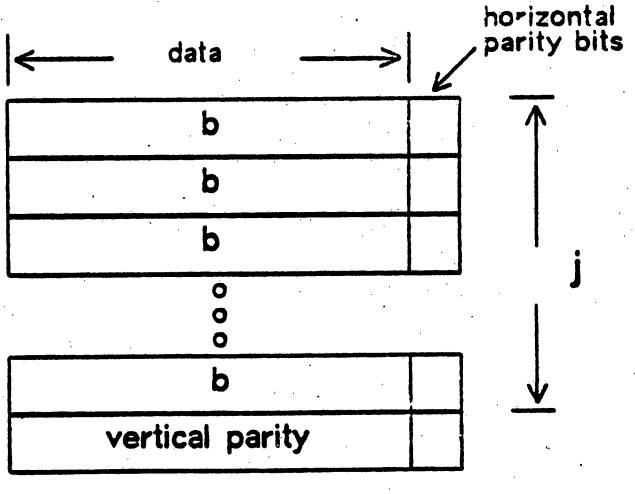
- $e < j * c$
- $k = j*b + c$

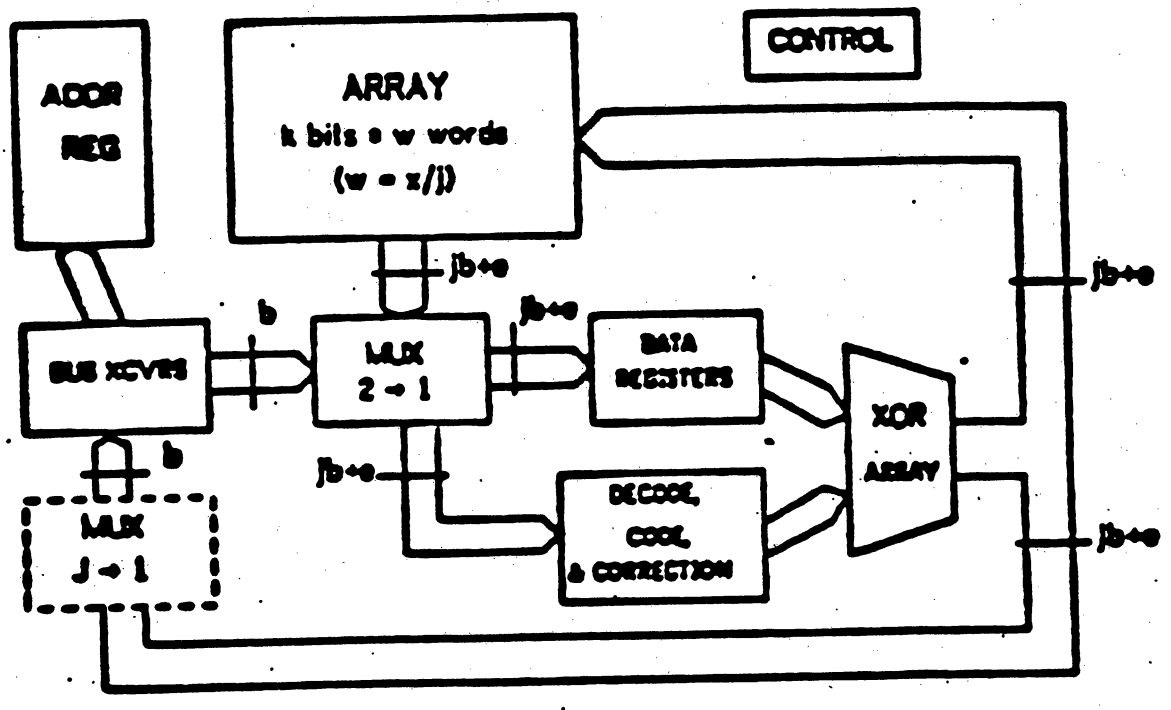
$w = x/j$

2. Block code

$k = (j + 1) *(b + 1)$

$w = x/j$





Hamming-Coded Memory Model

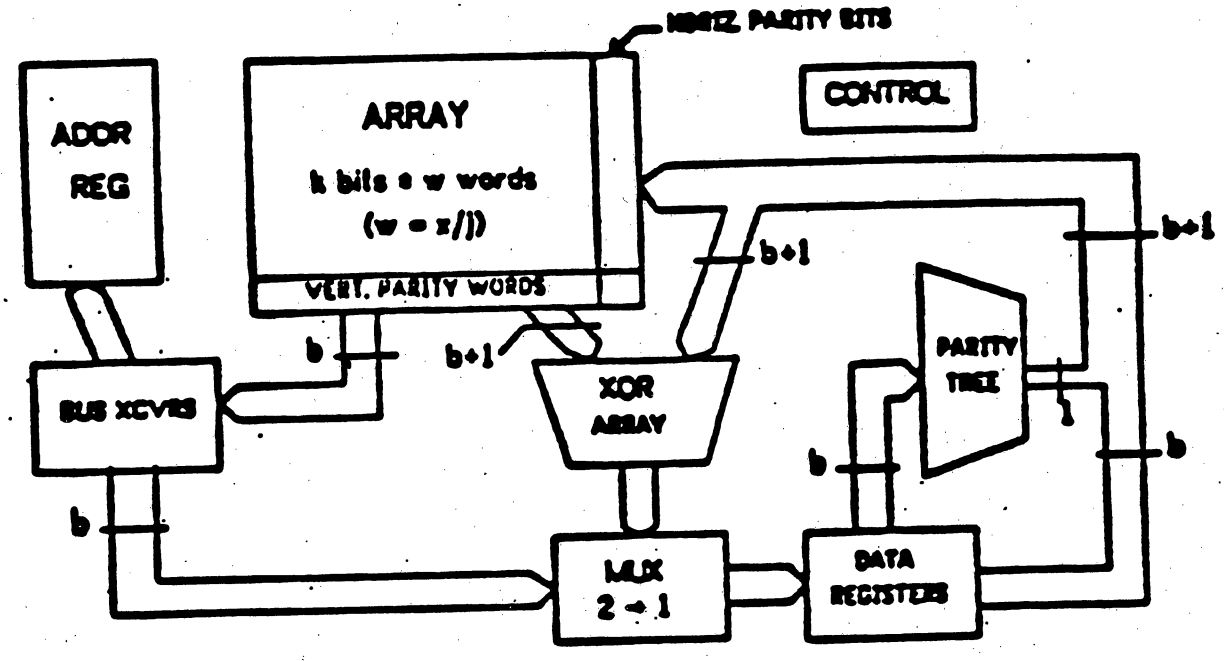
b bit logical words

x logical words

j logical words/physical word

e check bits/physical word

(x/j) physical words



Block-Coded Memory Model

b bit logical word

x logical words

b + 1 bit physical word

(x/j) additional physical words

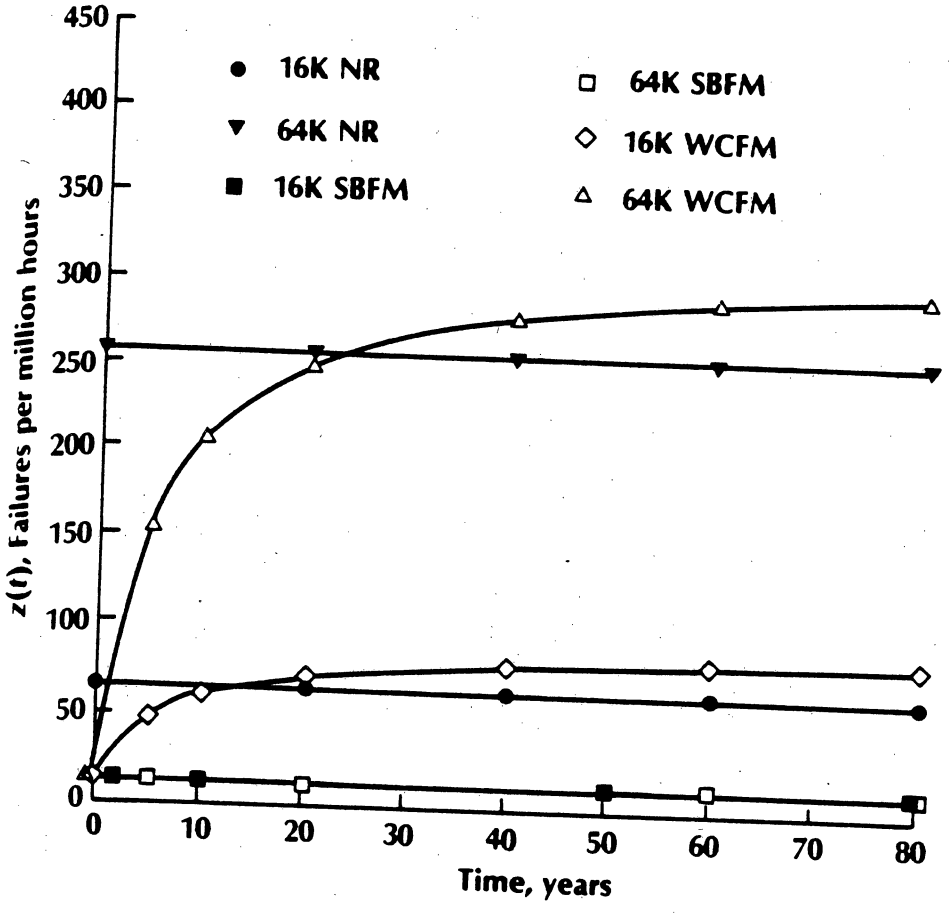


Figure 5–19. Comparison of hazard function.
(© 1980 IEEE.)

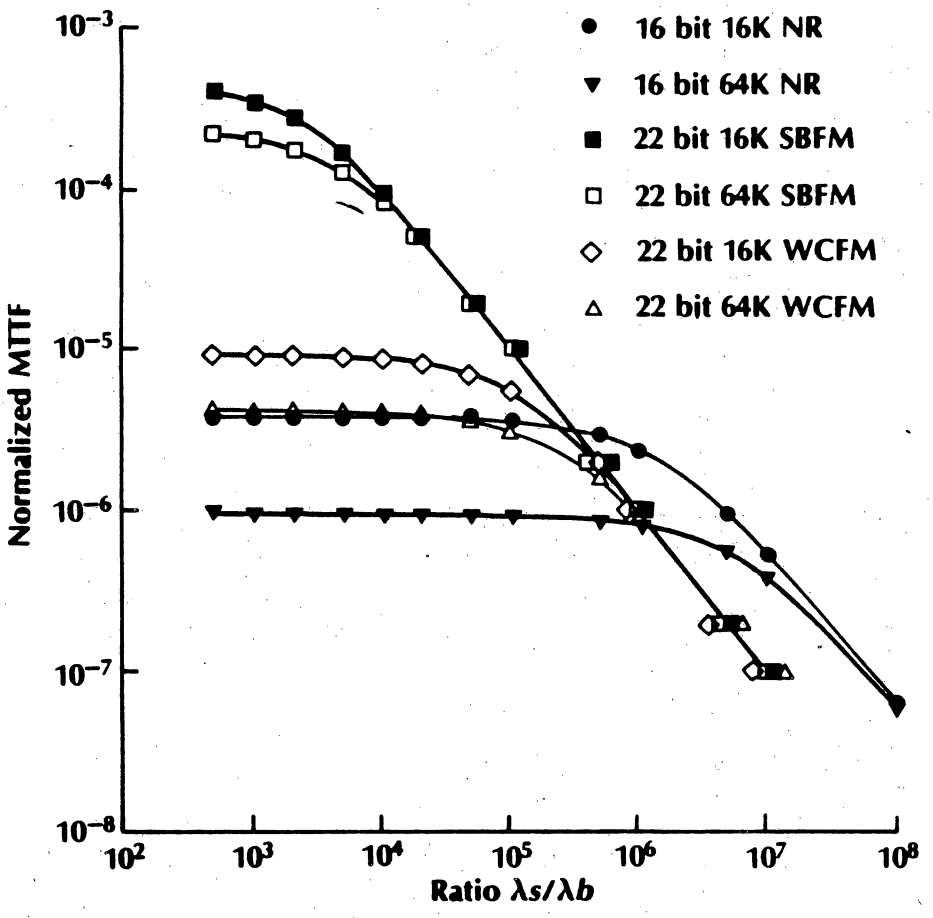


Figure 5–18. Comparison of MTTF. (© 1980 IEEE.)

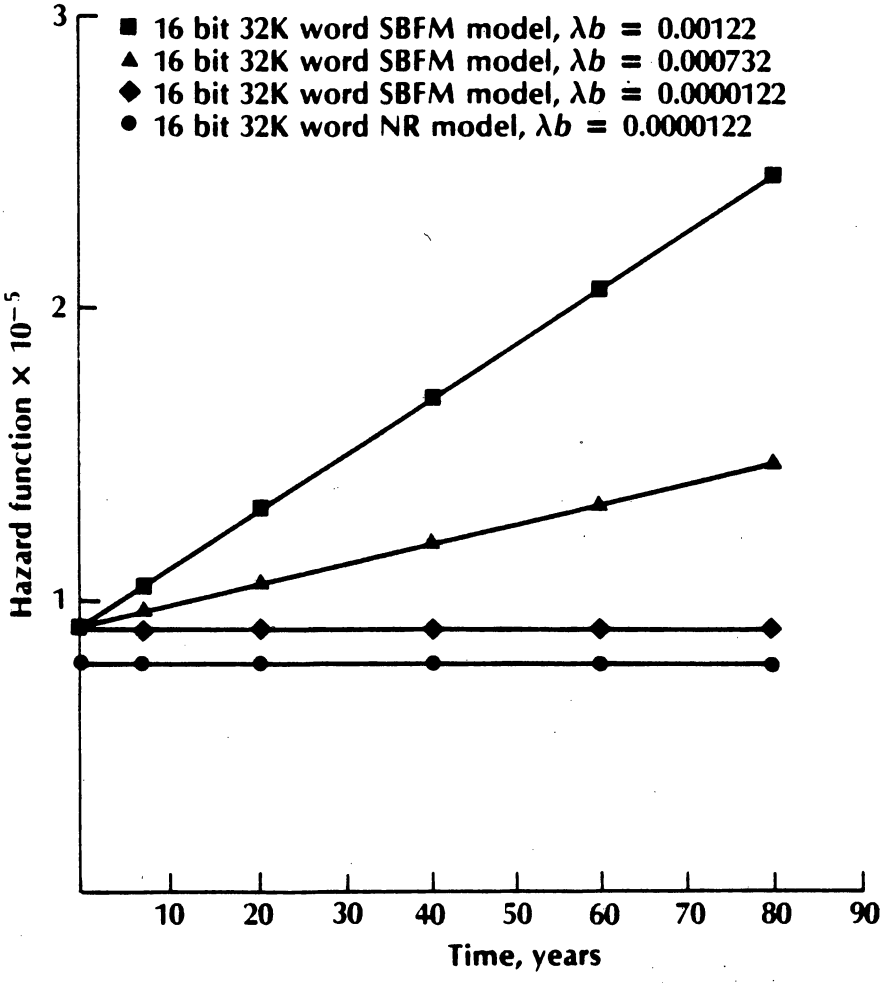


Figure 5–20. Sensitivity of the hazard function to λ_b.

Summary of Reliability Modeling

- Memory chip contribution to unreliability is negligible over a wide range of word size and memory size.

$\Rightarrow$ Control circuitry dominates unreliability

Performance in presence of failures

- Main memory expected degradation

  Call accessing patterns, Hamming and Block Code)

$$\frac{n\varepsilon}{\omega}$$

n = number of failures

ω = number of words in memory

ε = fraction of a memory cycle degradation for correction

Microstore Expected Degradation

$$\frac{n\varepsilon}{\omega}$$

PROBABILITY DISTRIBUTION OF PERFORMANCE DEGRADATION

(HAMMING CODE)

(PDP-11 CLASS MACHINE)

DEGRADATION	PROBABILITY
$< .001$	.657
$< .01$	.269
$< .02$	.023
$< .06$	.051

PROBABILITY DISTRIBUTION OF PERFORMANCE DEGRADATION

(BCC)

(VAX-11/780 CLASS MACHINE)

DEGRADATION	PROBABILITY
< .001	.048
< .01	.607
< .02	.167
< .05	.036
< .1	.083
< .2	.024
< .7	.035

Conclusions

- memory chip failure modes affect system reliability and dictate the choice of models for reliability

- these models provide good tools for design tradeoff analyses

- ECC memories are not automatically more reliable than NR memories, since their reliability is strongly influenced by the reliability of the control circuitry, and possibly dominated by it

    - a strong argument for LSI control circuitry

- ECC memories experience negligible performance degradation with errors present, in most cases

- Block coded memories, while more reliable than Hamming coded memories, experience slightly more degradation in the presence of errors, although the degradation is usually negligible

Reconfiguration

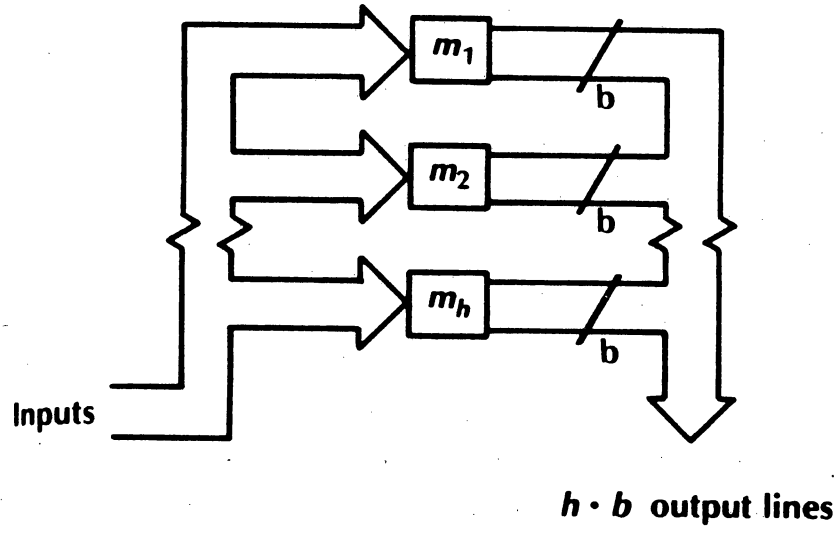
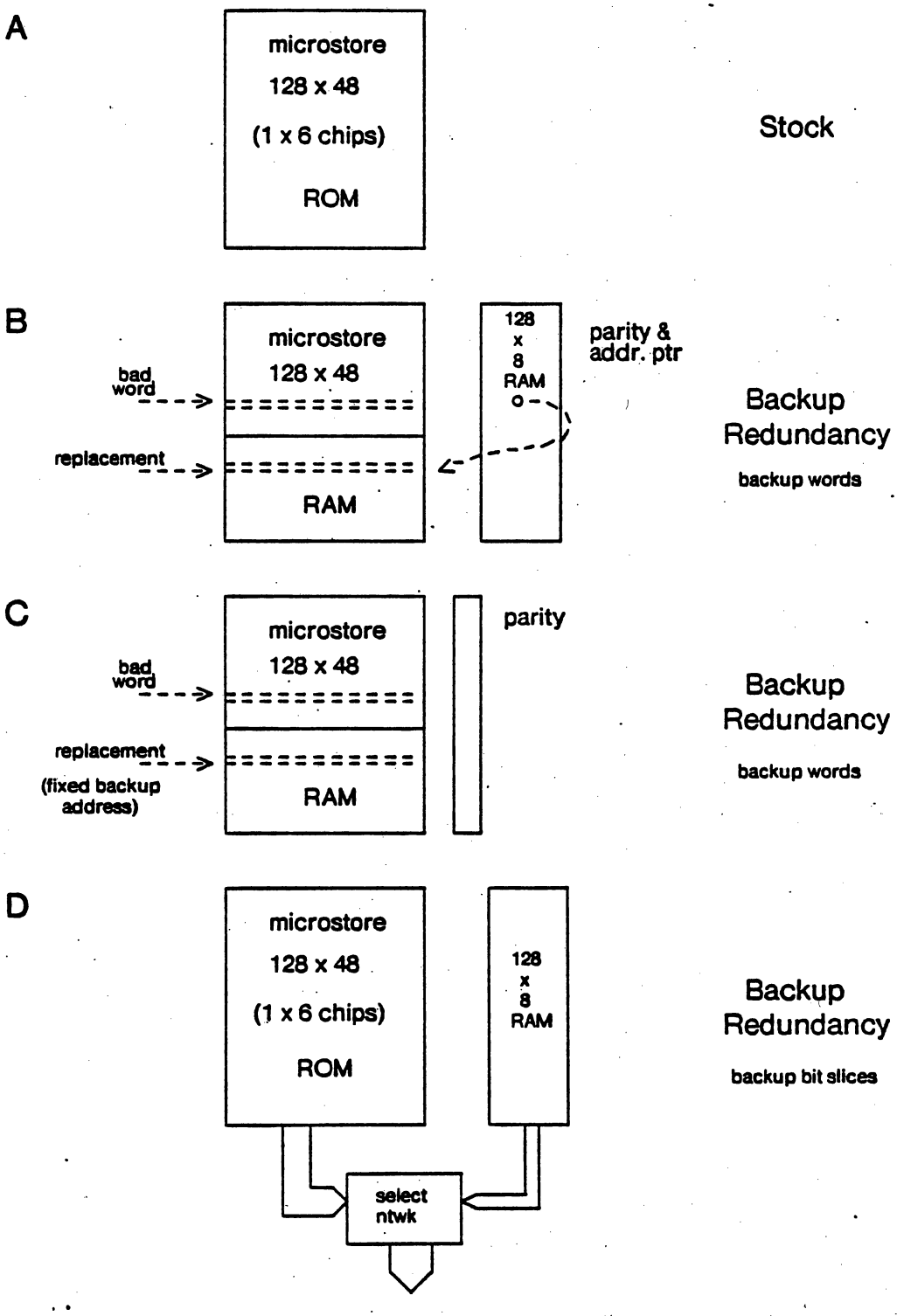


Figure 3–78. Circuit design of parallel byte-wide modules.


A
microstore
128 x 48
(1 x 6 chips)
ROM
Stock
B
microstore
128 x 48
bad word
replacement
RAM
128 x 8 RAM
parity & addr. ptr
Backup Redundancy
backup words
C
microstore
128 x 48
bad word
replacement
(fixed backup address)
RAM
parity
Backup Redundancy
backup words
D
microstore
128 x 48
(1 x 6 chips)
ROM
128 x 8 RAM
select ntwk
Backup Redundancy
backup bit slices

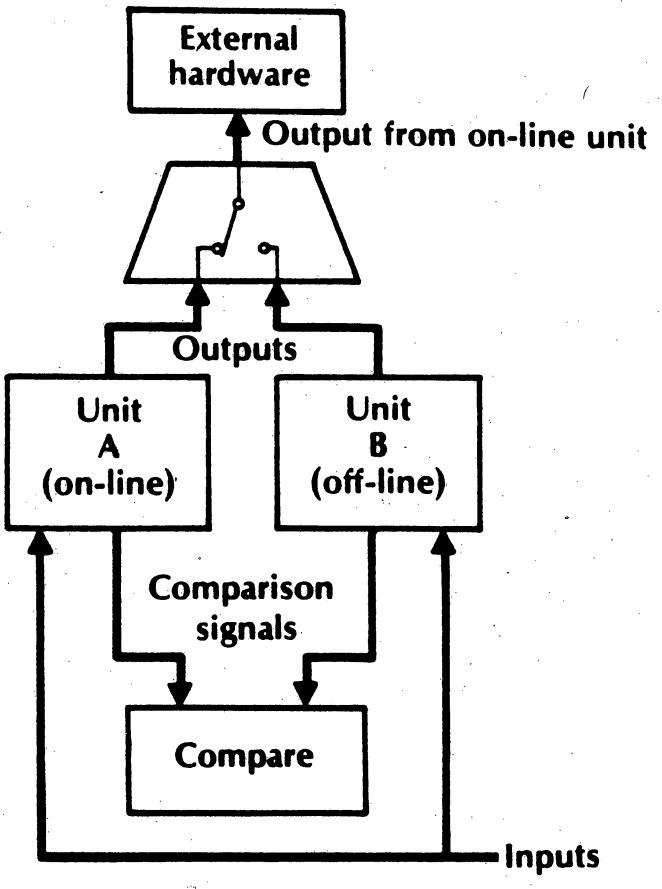


Figure 3–69. Reconfigurable duplication. A detected mismatch during comparison of characteristic signals triggers reconfiguration.

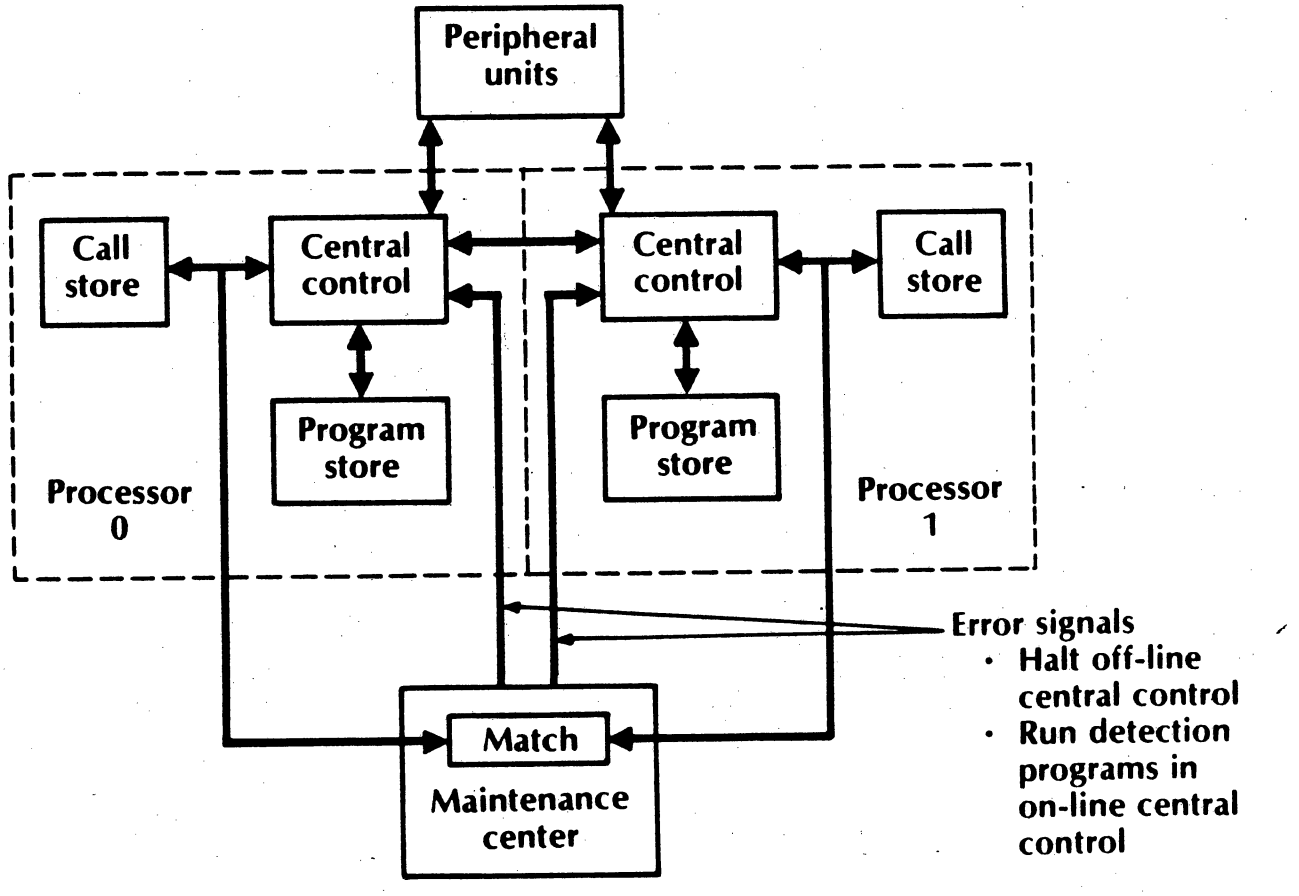
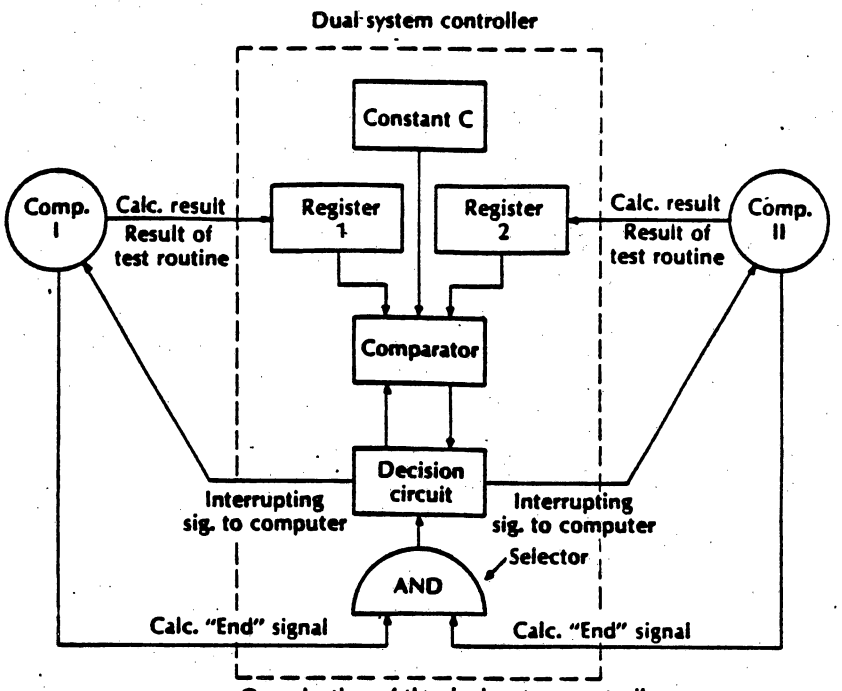
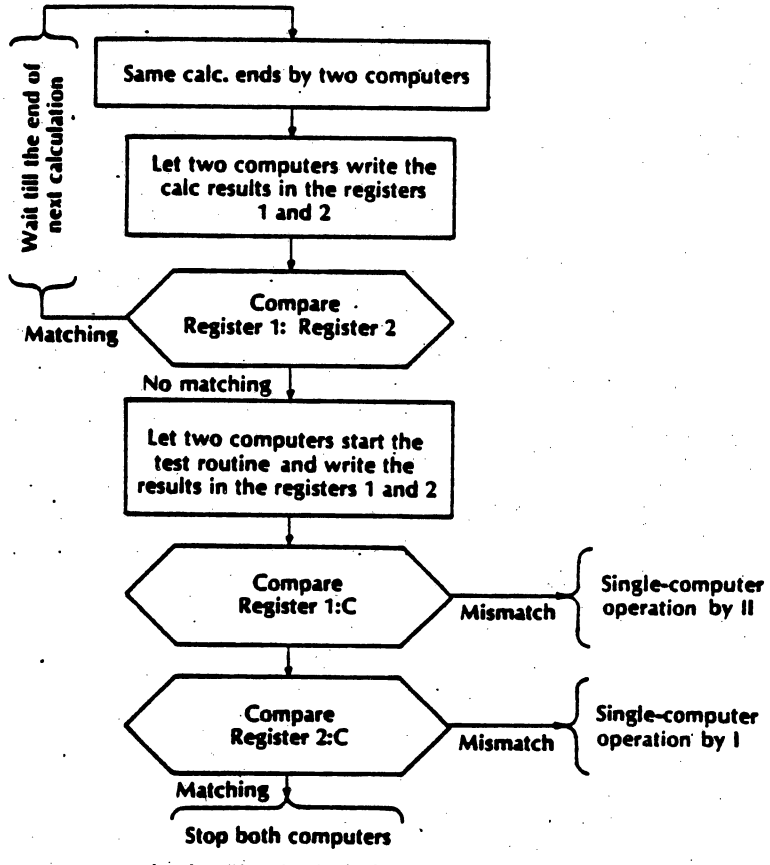


Figure 3–70. Reconfigurable duplication in Bell ESS-2. The two processors run synchronously; comparison of the call store input registers is performed constantly.



a. Organization of the dual system controller with respect to configuration control

Figure 3–71. Synchronization, matching, and reconfiguration in the COMTRAC computer. Synchronization and matching are performed at the task level, [Ihara et al., 1978]. (© IEEE 1978.)



b. Algorithm for fault detection by comparison, synchronization, and reconfiguration

Figure 3–71—*Continued*

Formulation of Markov Models

Every system has a set of opertional and failed "states", each of which represents a particular combination of working and failed modules.

=> For a system with N modules, the basic model has 2^N states.

Markov Assumptions

1. The probability of a given state transition depends only on the current state.

2. The length of time spent in a state does not influence either the probability distribution of the remaining time until the next transition or the probability of the next state transition path.

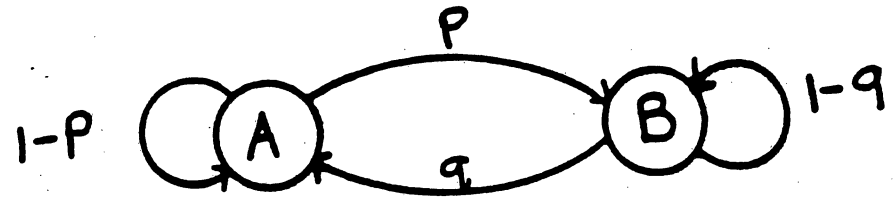
DIRECT RESULTS:

DISCRETE TIME WAITING TIMES ARE GEOMETRICALLY DISTRIBUTED

CONTINUOUS TIME WAITING TIMES ARE EXPONENTIALLY DISTRIBUTED

Discrete Time Markov Model

directed graph



A,B - states

p,q - transition probabilities

transition probability matrix

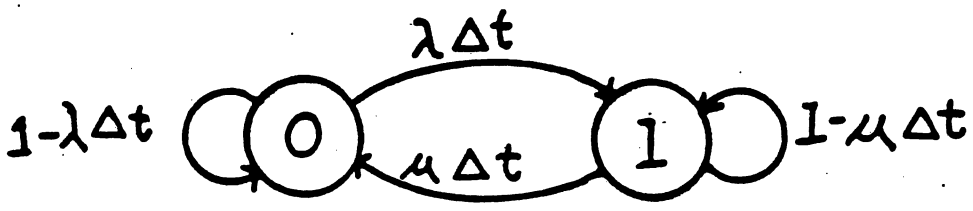
$$\begin{array}{c} \\ A \\ B \end{array} \begin{array}{c} \begin{array}{cc} A & B \end{array} \\ \begin{bmatrix} 1-p & p \\ q & 1-q \end{bmatrix} \end{array} = \Psi$$

$$[P_A^{k+1}, P_B^{k+1}] = [P_A^{k}, P_B^{k}] \times \Psi$$

$$\vec{P}(k+1) = \vec{P}(k) \times \Psi$$

Derivation of the Continuous Markov Model

let $p = \lambda \Delta t, \quad q = \mu \Delta t$



$$\vec{P}(t+\Delta t) = \vec{P}(t) \times \Psi$$

$$\vec{P}(t+\Delta t) = [P_0(t), P_1(t)] \times \begin{bmatrix} 1-\lambda\Delta t & \lambda\Delta t \\ \mu\Delta t & 1-\mu\Delta t \end{bmatrix}$$

$$P_0(t+\Delta t) = P_0(t)(1-\lambda\Delta t) + P_1(t)\,\mu\Delta t$$

$$P_0(t+\Delta t) = P_0(t) - \lambda P_0(t)\Delta t + \mu P_1$$

$$\frac{P_0(t+\Delta t) - P_0(t)}{\Delta t} = -\lambda P_0(t) + \mu P_1(t)$$

take limit as $\Delta t \longrightarrow 0$

$$\frac{dP_0(t)}{dt} = -\lambda P_0(t) + \mu P_1(t)$$

Derivation cont.

Similarly,

$$P_1(t+\Delta) = (1-\mu\Delta t)P_1(t) + \lambda \Delta t P_0(t)$$

$$\frac{dP_1(t)}{dt} = \lambda P_0(t) - \mu P_1(t)$$

$$\dot{P}_0(t) = -\lambda P_0(t) + \mu P_1(t)$$

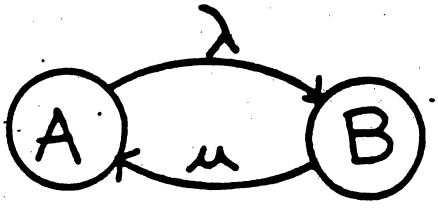
$$\dot{P}_1(t) = \lambda P_0(t) - \mu P_1(t)$$

$$\boxed{\vec{\dot{P}}(t) = \vec{P}(t) \times T}$$

$$T = \begin{bmatrix} -\lambda & \lambda \\ \mu & -\mu \end{bmatrix}$$

Continuous Time Markov Model

directed graph



A,B - states

λ, μ - transition rates

transition probability matrix

$$\begin{array}{c} \\ A \\ B \end{array}\begin{array}{c} \begin{array}{cc} A & B \end{array} \\ \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \end{array} = \Psi$$

waiting time parameter matrix

$$\begin{array}{c} \\ A \\ B \end{array}\begin{array}{c} \begin{array}{cc} A & B \end{array} \\ \begin{bmatrix} \lambda & 0 \\ 0 & \mu \end{bmatrix} \end{array} = \Lambda$$

$$\boxed{T = \Lambda(\Psi - I)} = \begin{bmatrix} -\lambda & \lambda \\ \mu & -\mu \end{bmatrix}$$

$$= \begin{bmatrix} \lambda & 0 \\ 0 & \mu \end{bmatrix} \begin{bmatrix} -1 & 1 \\ 1 & -1 \end{bmatrix}$$

2-State Markov Model cont.

$$P_0(t) = \frac{\mu}{\lambda+\mu} + \frac{\lambda}{\lambda+\mu} e^{-(\lambda+\mu)t}$$

$$= P_r\{\text{operational at time } t\}$$

$$P_1(t) = \frac{\lambda}{\lambda+\mu} - \frac{\lambda}{\lambda+\mu} e^{-(\lambda+\mu)t}$$

$$= P_r\{\text{failed at time } t\}$$

define Availability = $A(t) = P_0(t)$

steady state availability = $\frac{\mu}{\lambda+\mu}$

note that $MTTF = \frac{1}{\lambda}$

$$MTTR = \frac{1}{\mu}$$

some algebra: $\frac{\mu}{\lambda+\mu} = \frac{\frac{\mu}{\mu\lambda}}{\frac{\lambda}{\mu\lambda}+\frac{\mu}{\mu\lambda}}$

$$= \frac{\frac{1}{\lambda}}{\frac{1}{\mu}+\frac{1}{\lambda}}$$

steady state availability $= \frac{MTTF}{MTTR + MTTF}$

Steady State Calculations

to calculate only the steady state values, redo equation (1):

$\dot{P}_0(t)$ and $\dot{P}_1(t) \rightarrow 0$

$P_0(t)$ and $P_1(t) \rightarrow P_0$ and P_1

$$0 = -\lambda P_0 + \mu P_1$$
$$0 = \lambda P_0 - \mu P_1$$

remember - $P_0 + P_1 = 1$

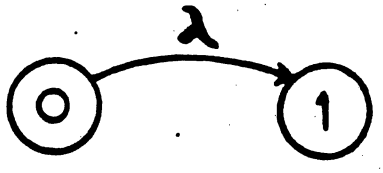
$$P_0 = 1 - P_1$$
$$P_0 = 1 - \frac{\lambda}{\mu} P_0$$
$$P_0 \left(1 + \frac{\lambda}{\mu}\right) = 1$$
$$P_0 \left(\frac{\mu + \lambda}{\mu}\right) = 1$$

$$\boxed{P_0 = \left(\frac{\mu}{\lambda + \mu}\right)}$$

$$\Rightarrow \boxed{P_1 = \frac{\lambda}{\lambda + \mu}}$$

Reliability of 2-State Model

In order to calculate the reliability rather than the availability, the failed state is made into a "trapping" state.



$$\Psi = \begin{bmatrix} 0 & 1 \\ 0 & 1 \end{bmatrix} \qquad \Lambda = \begin{bmatrix} \lambda & 0 \\ 0 & 0 \end{bmatrix}$$

$$T = \begin{bmatrix} \lambda & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} -1 & 1 \\ 0 & 0 \end{bmatrix} = \begin{bmatrix} -\lambda & \lambda \\ 0 & 0 \end{bmatrix}$$

applying $\dot{\vec{P}}(t) = \vec{P}(t) \times T$

$$\begin{cases} \dot{P}_0(t) = -\lambda P_0(t) \\ \dot{P}_1(t) = \lambda P_0(t) \end{cases}$$

$$A = [sI - T] = \begin{bmatrix} s+\lambda & \lambda \\ 0 & s \end{bmatrix}$$

Reliability of 2-State Model cont.

$$A^{-1} = \frac{1}{s(s+\lambda)} \begin{bmatrix} s & \lambda \\ 0 & s+\lambda \end{bmatrix}$$

$$\vec{P}(0) = [1\ 0] \begin{bmatrix} \frac{s}{s(s+\lambda)} & \frac{\lambda}{s(s+\lambda)} \\ 0 & \frac{s+\lambda}{s(s+\lambda)} \end{bmatrix}$$

$$\pi_0(s) = \frac{s}{s(s+\lambda)} = \frac{1}{s+\lambda}$$

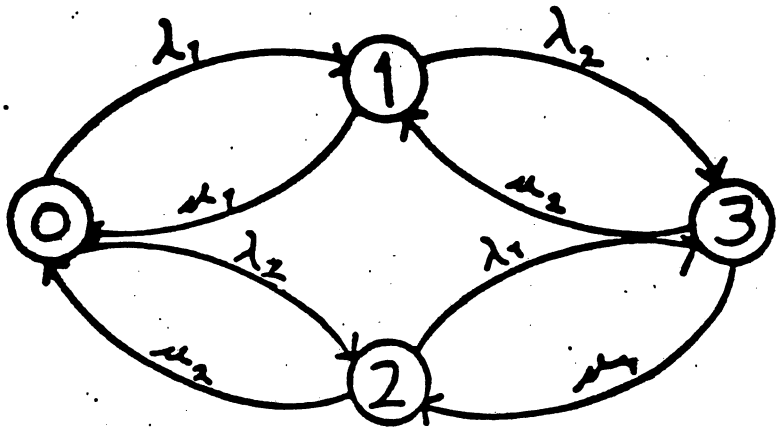
$$\pi_1(s) = \frac{\lambda}{s(s+\lambda)} = \frac{1}{s} - \frac{1}{s+\lambda}$$ by partial fraction expansion

taking the inverse transform,

$$P_0(t) = e^{-\lambda t} = R(t) - \text{as expected}$$

$$P_1(t) = 1 - e^{-\lambda t}$$

Example: Dual Processor System



λ_i = failure rate of processor i

μ_i = repair rate of processor i

state 0: both operational

state 1: processor 1 failed

state 2: processor 2 failed

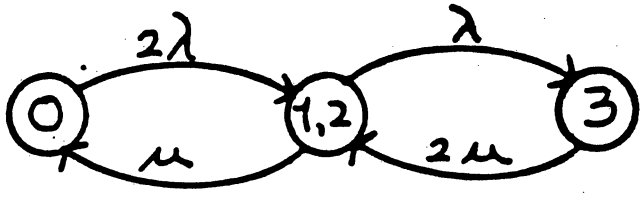
state 3: both failed

Dual Processor cont.

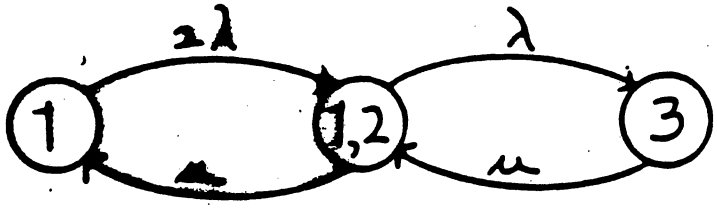
often, assume $\lambda_1 = \lambda_2 = \lambda$

$\mu_1 = \mu_2 = \mu$

then the previous model can be collapsed to



NOTE THAT THIS MODEL ASSUMES AS MANY REPAIRMEN AS FAILED MACHINES. IF ONLY ONE REPAIRMAN IS AVAILABLE, THE MODEL BECOMES



IF all you're interested in is steady state, no average.

Combinatorial

$$A_{sys} = 1 - (1-A)^2$$
$$= 2A - A^2$$

Queuing Model

M/M/c/k/k

$$P_n = \left(\frac{k-n+1}{n}\right)(\lambda/\mu)\, P_{n-1}$$
$$n = 1, 2, \ldots c$$

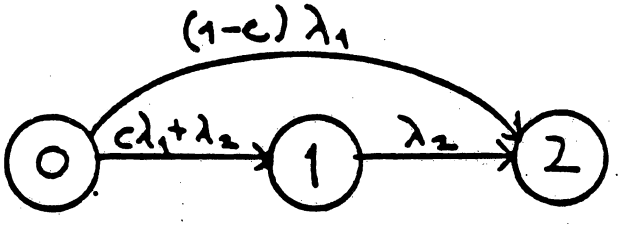
$$P_n = \left(\frac{k-n+1}{c}\right)(\lambda/\mu)\, P_{n-1}$$

$$A_{sys} = P_0 + P_1$$
$$= \frac{\mu^2 + 2\lambda\mu}{\mu^2 + 2\lambda\mu + \lambda^2}$$
$$= \frac{\mu^2}{(\mu+\lambda)^2} + \frac{2\lambda\mu}{(\mu+\lambda)^2}$$
$$= A^2 + 2\frac{\mu}{\mu+\lambda}\left(\frac{\lambda}{\mu+\lambda}\right)$$
$$= A^2 + 2A(1-A)$$
$$= 2A - A^2$$

COVERAGE

For real systems, fault diagnosis and isolation is far from perfect.

=> Coverage (usually denoted c) is defined as the conditional probability that a system recovers given there was a failure.



$$R_{sys} = R_1 + cR_2(1-R_1)$$

for $R_1 = R_2 = R$

$$R_{sys} = R + cR(1-R)$$

$$R_{sys} = (1+c)R - cR^2$$

for $c = 1$, $R_{sys} = 2R - R^2$

COVERAGE cont.

for a parallel system with n units (n-1 spares) each with identical reliability R and coverage c

$$R_{sys} = R \sum_{i=0}^{n-1} c^i (1-R)^i$$

evaluating the geometric progression,

$$R_{sys} = R \left(\frac{1 - c^n (1-R)^n}{1 - c(1-R)} \right)$$

$$R_{sys} = R \left(\frac{1 - (cQ)^n}{1 - cQ} \right)$$

EFFECT OF COVERAGE

for R = 0.9,

Table of R_{sys}

c \ n	2	4	∞
0.8	.9720	.9782	.9783
0.9	.9810	.9889	.9890
0.99	.9891	.9988	.9889
1.0	.9900	.9999	1.0000

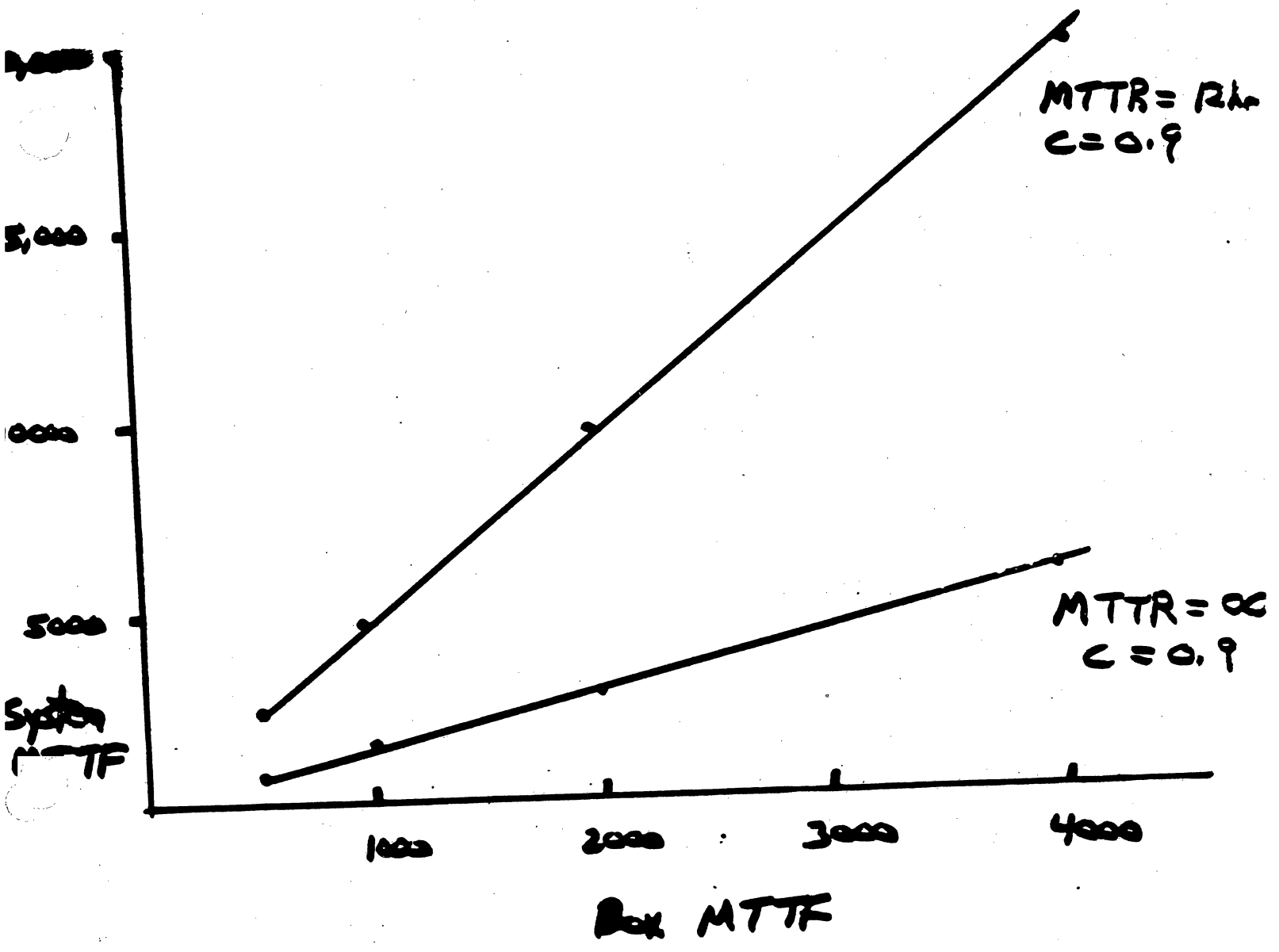
$$MTTF(n \text{ modules}) = \int_0^\infty R(t) \sum_{i=0}^{n-1} c^i (1-R(t))^i \, dt$$

$$= MTTF(n-1 \text{ modules}) + \int_0^\infty R(t)\, c^{n-1} (1-R(t))^{n-1} \, dt$$

let $R(t) = e^{-\lambda t}$, and integrate,

$$= MTTF(n-1 \text{ modules}) + \frac{c^{n-1}}{n\lambda}$$

$$= \frac{1}{\lambda c} \sum_{i=1}^{n} \frac{c^i}{i}$$



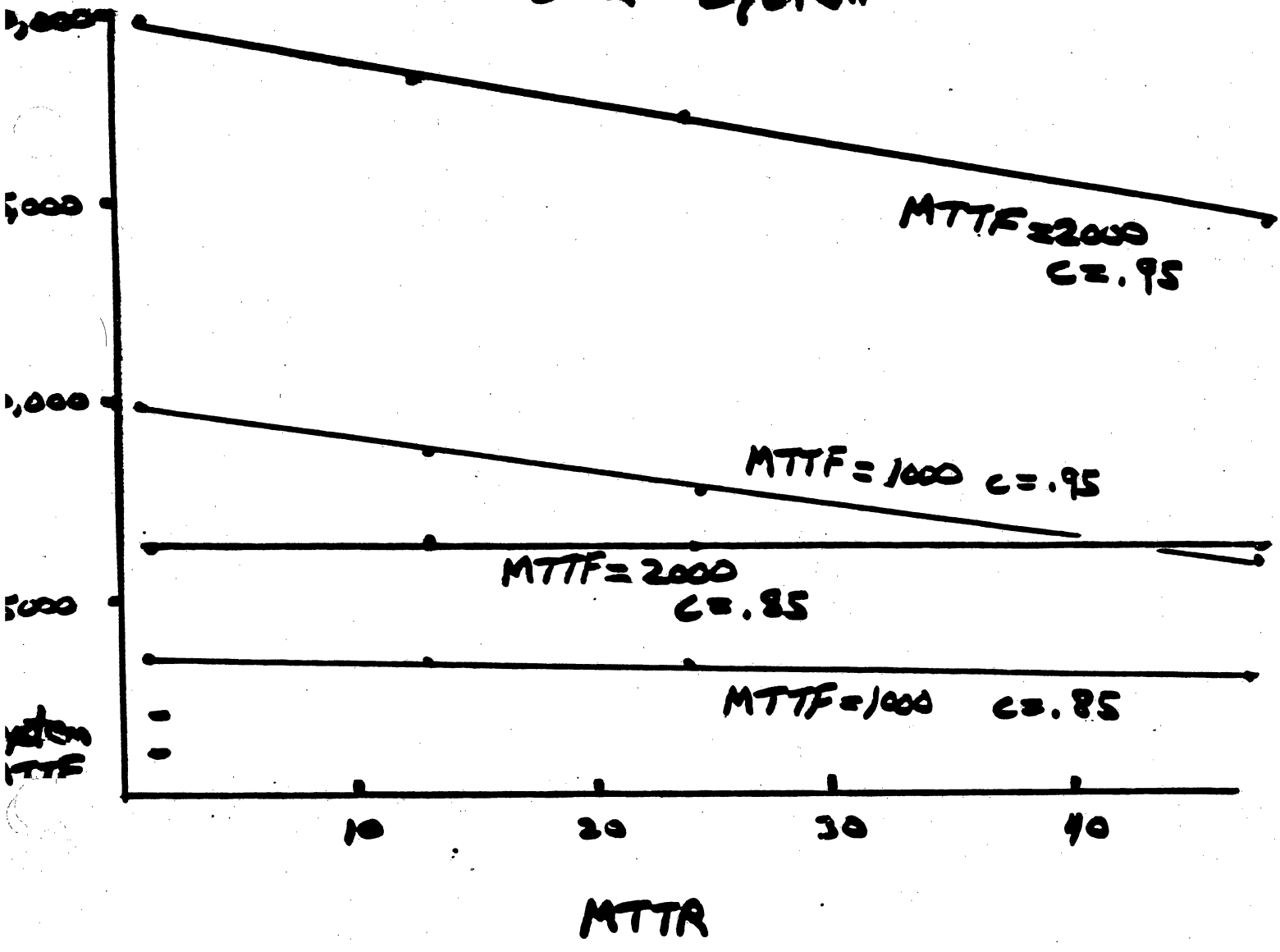
⇒ differences in models

MTTR = ∞ easy

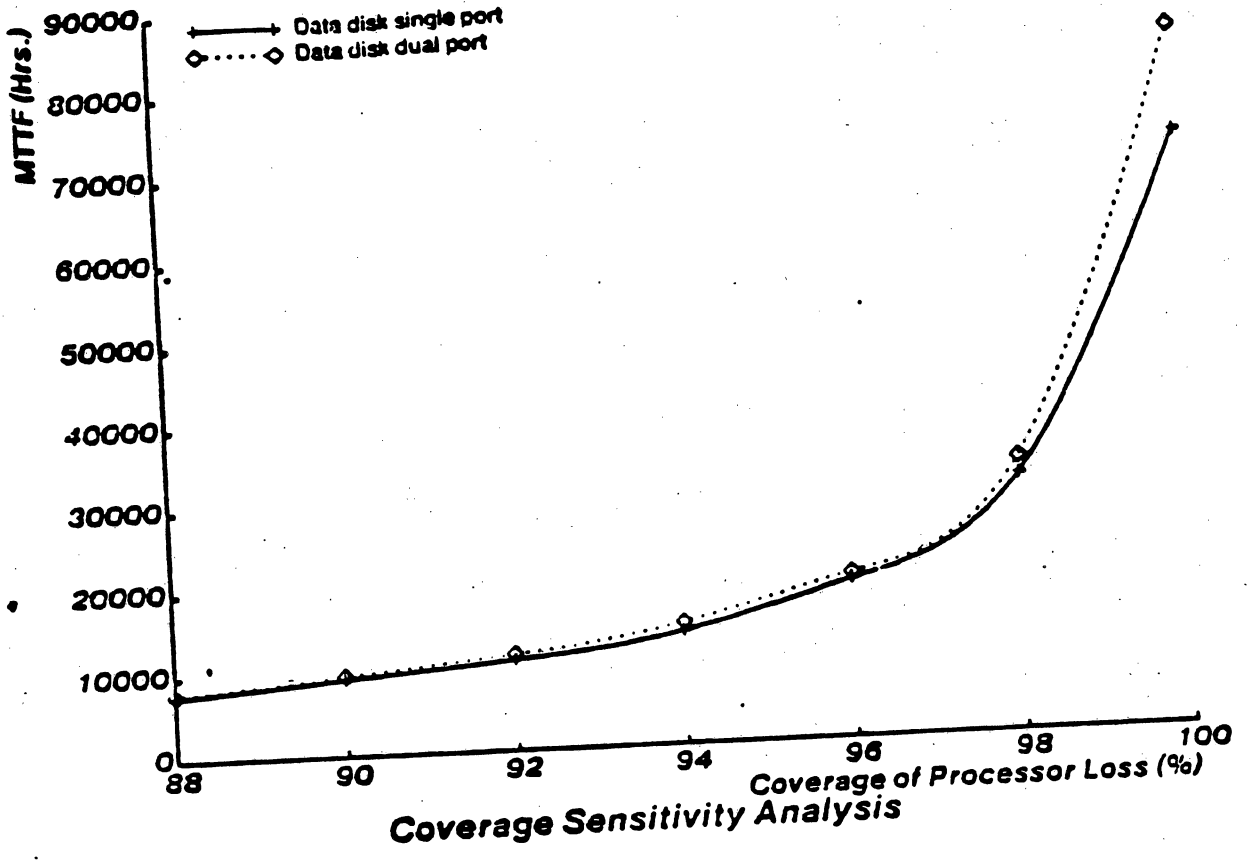
MTTR = finite exponentially hard

dual system a 1 week

Dual System



⇒ c more important than MTTF



Coverage Sensitivity Analysis

Reliability Evaluation: Available Modelling Tools

- Parts count models (ORACLE, ARPP)
- Combinatorial (CARE II, ADVISER)
- Markov models (ARIES 82)
- Semi-Markov models (CARE III, HARP)
- Event-driven simulator (SIMPLE)
- General modeller (RAT)

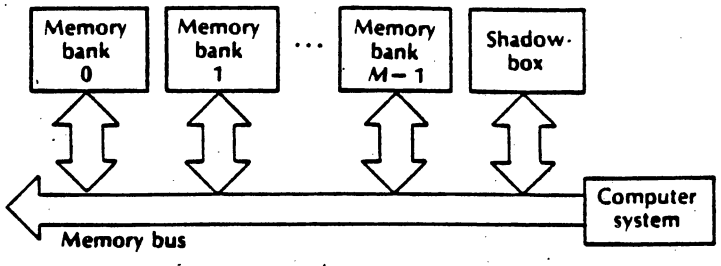


Figure 3–80. The shadow box memory backup technique proposed by Arulpragasm and Swarz.

RECOVERY
Retry

- transient error solution

- Ethernet
- busses

UNIVAC 1100/60
programmable pause

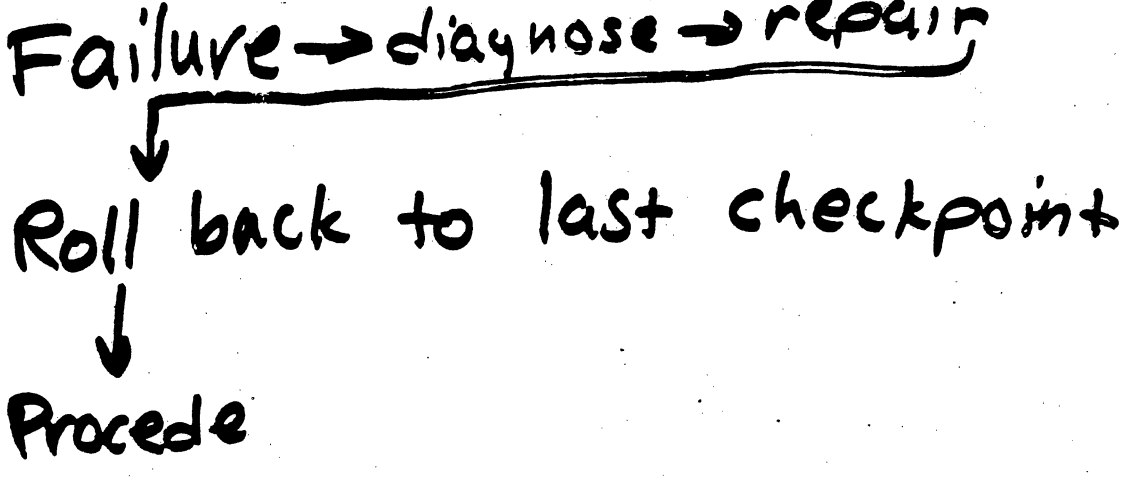
- instruction retry
- process retry

⇒ rollback

Alternate Data retry

Checkpoint & Rollback

Periodically, store all state information needed to successfully complete task.



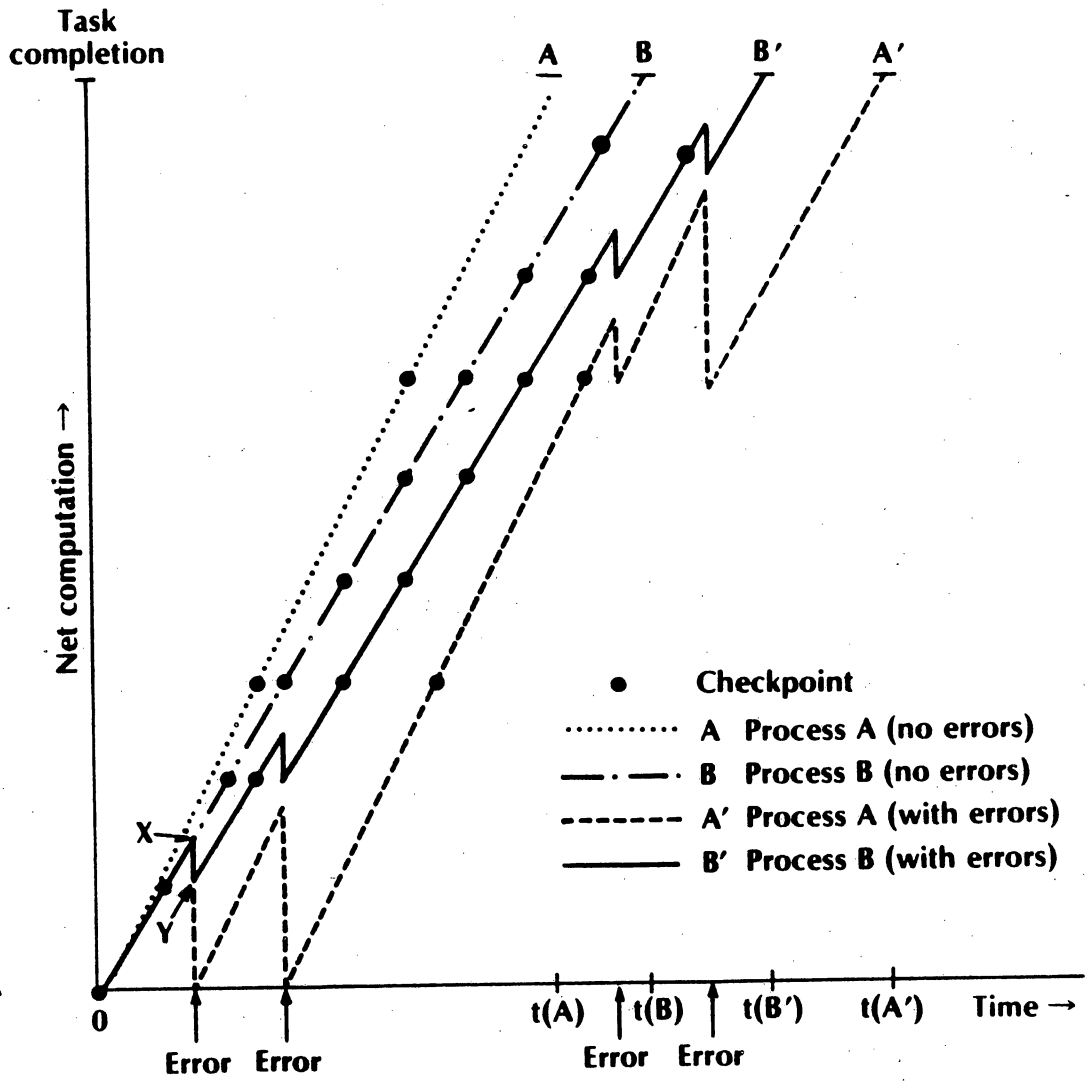


Figure 3–91. Scenario of two processes, identical except for checkpoint frequency.

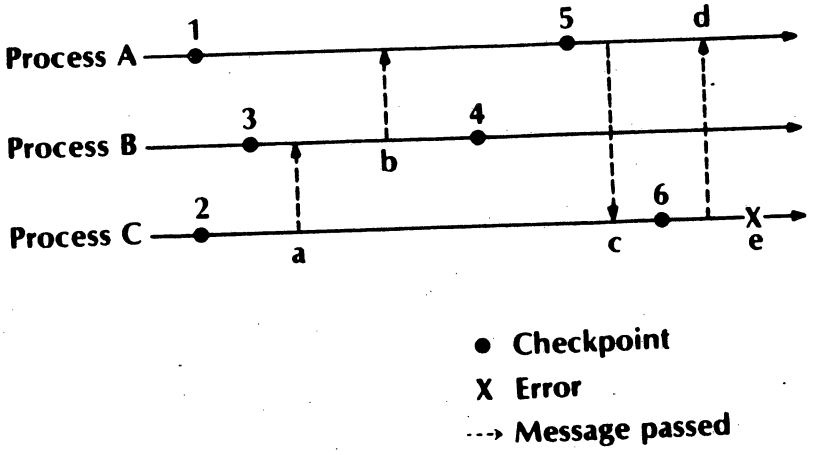
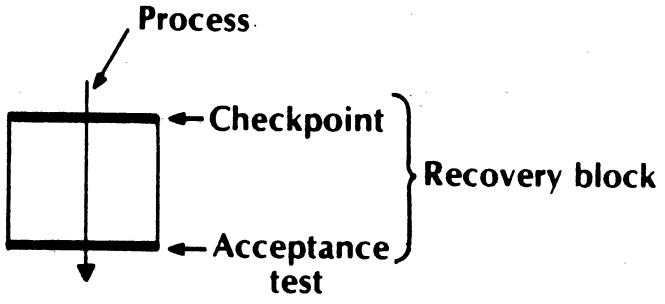
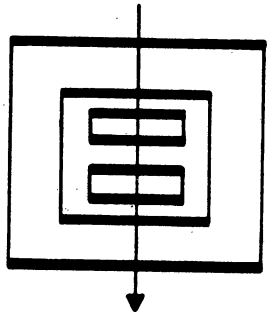


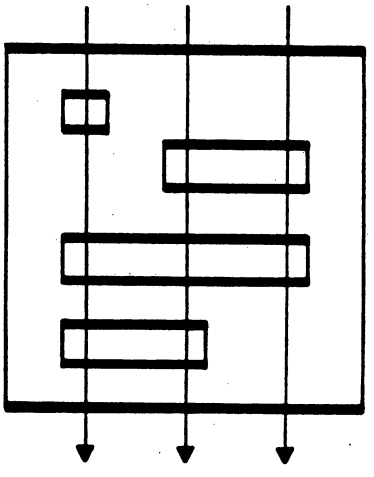
Figure 3–92. Cooperating checkpointing processes. A failure at point *e* forces process C to roll back to checkpoint 6. Because of a message sent by process C, process A must then be rolled back to checkpoint 5. Rolling back of the processes in this fashion eventually requires all three processes to be rolled back to their initial checkpoints.



a. Graphic notation for a recovery block



b. Nesting of recovery blocks



c. Multiprocess recovery blocks

Figure 3–94. Use of Randell's graphical notation to demonstrate extensions beyond the simple recovery block.

Journalling

Save initial state,
record list of
commands/changes/operations

Failure → diagnose → repair

↓

start from beginning,
recreate state just
before failure

e.g., Bravo

Graceful Degradation

Allow system capacity to Degrade in the event of failures, but still operate.

- can use "excess" to boost capacity before failures occur.
- useful computing performed a factor

Examples:

SIFT, FTMP, PLURIBUS
Cm*, C.mmp, TANDEM — Software use of "Hooks"
VAX-11/780, 1100/60

Support for Reliability Modelling Concepts

Concept	*Packages Supporting*
Measures	
λ	Lambda
MTTF	Lambda, SEC3, SEC4, MARK1
MT(r)	Lambda
MTI(r)	(Lambda)
R(t) (and MR(t))	Lambda, SEC3, SEC4
A	MARK1 (Lambda)
MTTC	MARK1
MTBPR	Lambda
MTBF, MTBC	none
Repair	
Modelling	none
Effect on Reliability	MARK1 (Lambda)
ult Detection Coverage	
Modelling	none
Effect on Reliability	MARK1 (Lambda)
Fault Handling Coverage	
Modelling	(MARK1)
Effect on Reliability	MARK1 (Lambda)
Transient/Intermittent Failures	
Modelling	none
Effect on Reliability	MARK1
General z(t)	
Modelling	none
Effect on Reliability	(Lambda)
Diagnosability	none
Performability	none

Lambda Library Functions and Procedures

Name	*Type*	*Purpose*
Reliability Models		
REL_TMR	function	TMR module reliability (majority-vote)
REL_NMR	function	NMR module reliability (majority-vote)
M_OF_N	function	*m*-out-of-*n* modules reliability
SEC_MEM	function	SEC code memory reliability
ECC_MEM	function	General ECC code memory reliability
DUAL	function	Reconfig. duplication, with coverage
DUAL_REPAIR	function	Reconfig. duplication, with repair
Miscellaneous		
IC_THETA	function	Θ_{ja} model for DIPs
CUSTOMLAMBDA	function	Mil-217D model for PC board λ
MTTF_STATS	procedure	Print statistics on MTTF integration

Design for Testability and Maintainability

DESIGN FOR SYSTEM RELIABILITY

8 Design for Testability & Maintainability

OBJECTIVES

* A brief survey of Design for Maintainability
* Symptom Directed Diagnosis
* Trend Analysis
* Commercial architectures

Table 4–7. Design for testability-added hardware types.

Test points
Edge connectors
Dual In-line Package (DIP) sockets
Terminal posts
Tristate drivers
IC clips
Pull-up resistors
Pin amplification
Input demultiplexers
Output multiplexers
Parity trees
Blocking gates
Control and observation switching
Disconnection structures
Edge connectors
DIP sockets
Tristate drivers
Blocking gates
Test-state register
Power-up reset
Scan-in/scan-out shift registers

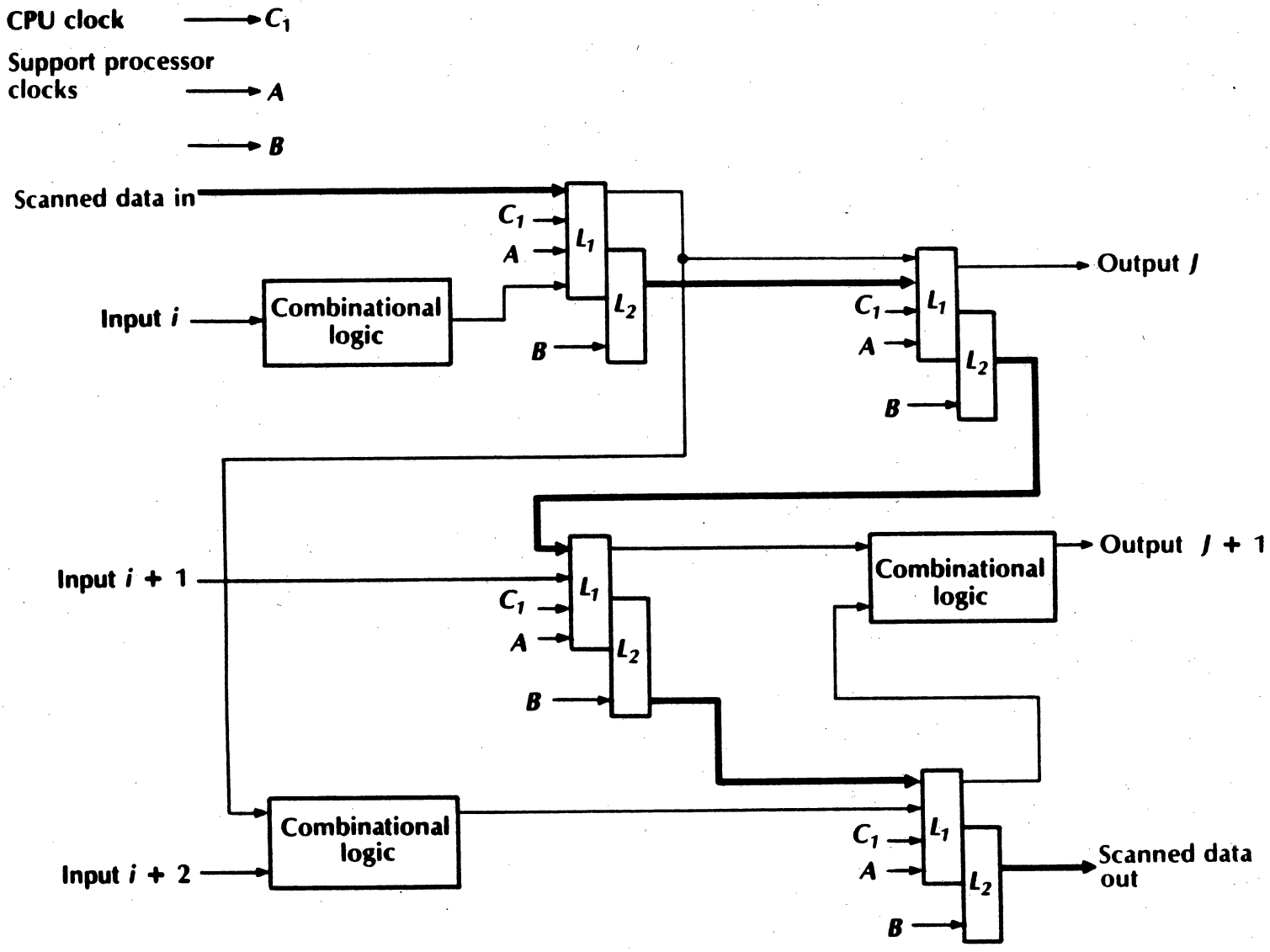


Figure 4–8. An example of LSSD.

Table 4–8. Design for testability-added hardware location suggestions.

1. Make sequential circuit components such as counters, shift registers, and control flip-flops initializable. Some ways of providing initializability are to wire control signals or testpoints to component clear or preset inputs, or to provide direct-load capabilities. Do not tie both the set and preset inputs of flip-flops to a common permanent logic signal.
2. Make counter chains controllable and observable in a reasonably short test sequence. For example, break long counter chains during test mode by inserting testpoints in the carry-propagate/count-control lines. This is especially important in the case of clock countdown circuits that are used to provide control inputs for the rest of the circuit. In the latter case it may even be wise to provide testpoints to bypass the counters entirely during portions of the test.
3. On-board clock oscillators should be made disconnectable during test. This can be done by disconnecting their output with a testpoint or by socketing them for removal during test.
4. If one-shots are used, control and observe their outputs with testpoints.
5. Try to break global feedback loops during test mode. Blocking gates can be used for this, rather than more costly testpoints.
6. Use added hardware to partition the circuit into functionally independent subcircuits for testing. This is especially important for separating digital and analog subcircuits. One method is to place testpoints between subcircuits.
7. Break reconvergent fan-out paths when they interfere with testability.
8. Place testpoints at locations of high fan-out or high fan-in.
9. Route logic drives of lamps and displays to testpoints so that the tester can check for correct operation. Make keyboard and switch outputs accessible to the test machine by breaking with testpoints.
10. In circuits containing microprocessors and other LSI devices, use testpoints to enhance controllability and observability of address buses and data buses, important control signals such as the reset and hold inputs to the microprocessor, and bus tristate control. In particular, the address and data terminals of RAMs and ROMs should be easily accessible.

Table 4–9. Design for testability suggestions not requiring added hardware.

1. Avoid the use of asynchronous sequential circuits. Edge-triggered *D*-type flip-flops are preferable to other types of flip-flops. These are synchronous, and behave merely as clocked data delays during testing.
2. Avoid one-shots when possible.
3. Avoid unnecessary wired-OR or wired-AND connections. When these must be used, try to employ gates from the same IC package to enhance fault locations.
4. Use elements in the same IC package when designing a series of inverters.
5. Try to assign gates in a feedback loop to the same IC package.

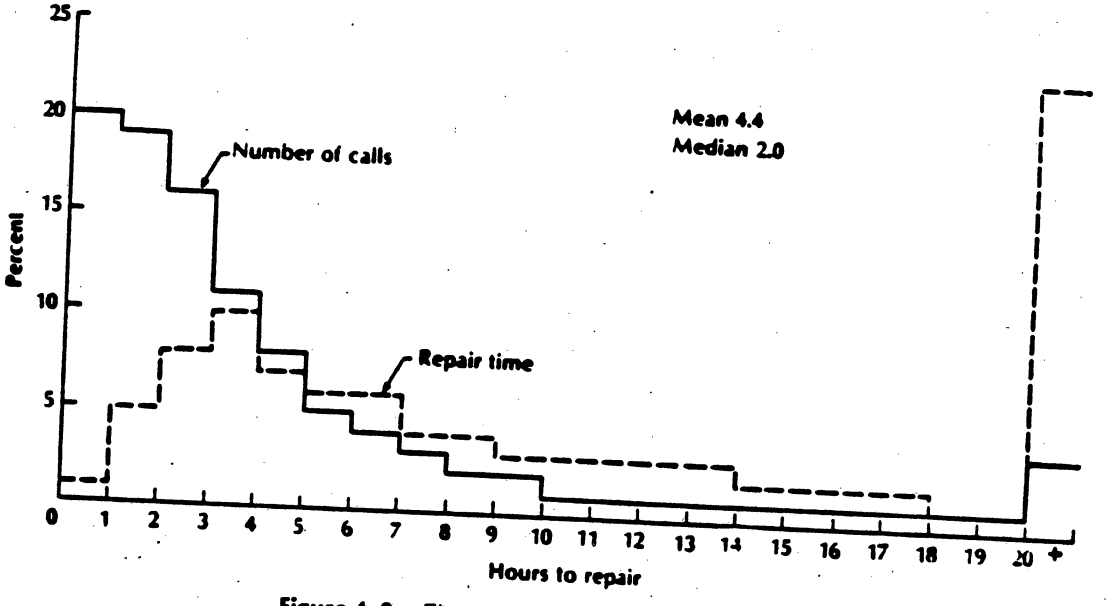


Figure 4–9. Time To Repair (TTR) distribution.

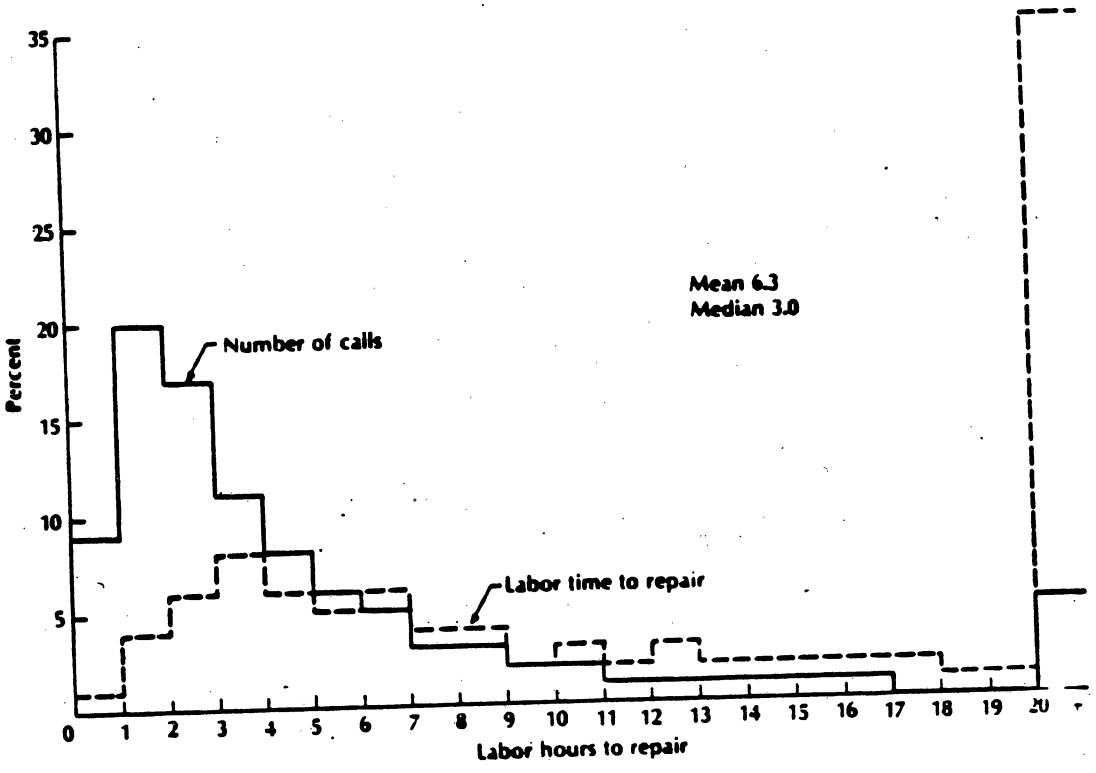


Figure 4–10. Labor Hour to Repair (LH) distribution.

Table 4–10. Suggestions on design for maintainability.

1. Start small. Verify subsystem operation step by step, from the minimal logic configuration through the addition of each incremental function.
2. Provide isolated environments so that each subsystem is completely exercised without requiring other subsystems.
3. Provide subsystem self tests, including tests of error-detection circuitry.
4. Provide internal observability and controllability in subsystems.
5. Provide error reporting and logging.
6. Minimize the need for external test equipment [illegible]
7. Provide a cabinet structure that facilitates repair.
8. Base repair strategies on component replacement, not on component swap.
9. Provide a support processor and remote access for diagnosis.

DIAGNOSIS

To identify a condition by its signs, symptoms, or distinguishing characteristics.

To infer a process that generated a set of symptoms, outcomes, or results.

Diagnosis is *not* testing. Diagnosis is a problem-solving procedure whose goal is to guide the administration of tests.

Testing is a procedure whose goal is to provide information sufficient for determining whether or not a unit under test responds to a stimulus in accordance with a prespecified standard.

```
V A X / V M S   SYSTEM ERROR REPORT   COMPILED 17-JUN-1985 14:39
********************* ENTRY      16. ***************************
ERROR SEQUENCE 199.                          LOGGED ON SID 02006EFF
MACHINE CHECK, 31-MAR-1985 22:59:02.04 KA750 REV# 255. MIC# 94.
     EXCEPTION PC     80008E57
     ERROR PSL        04070004
                                  Z-BIT
                                  INTERRUPT PRIORITY LEVEL = 07
                                  PREVIOUS MODE = KERN
                                  CURRENT MODE  = KERNEL
                                  INTERRUPT STACK

     SUMMARY CODE     00000002
                                  TRANSLATION BUFFER OR BUS ERROR

     VA LAST REF      80060243
     PC AT ERROR      80008E57
     MDR              0000005D
     SMR              00000008
                                  CPU MODE = KERNEL
                                  VIRTUAL
                                  READ

     RLTO             00000000
     TBER             00000003
                                  TB G0 DATA ERROR
                                  TB G1 DATA ERROR

     CAER             00000001
                                  CACHE HIT

     BER              00000000
     MCESR            00000006
                                  XB REFERENCE
                                  TB PARITY ERROR
```

Event Log

ANALYZING EVENT LOGS

Information Reduction

Information Organization

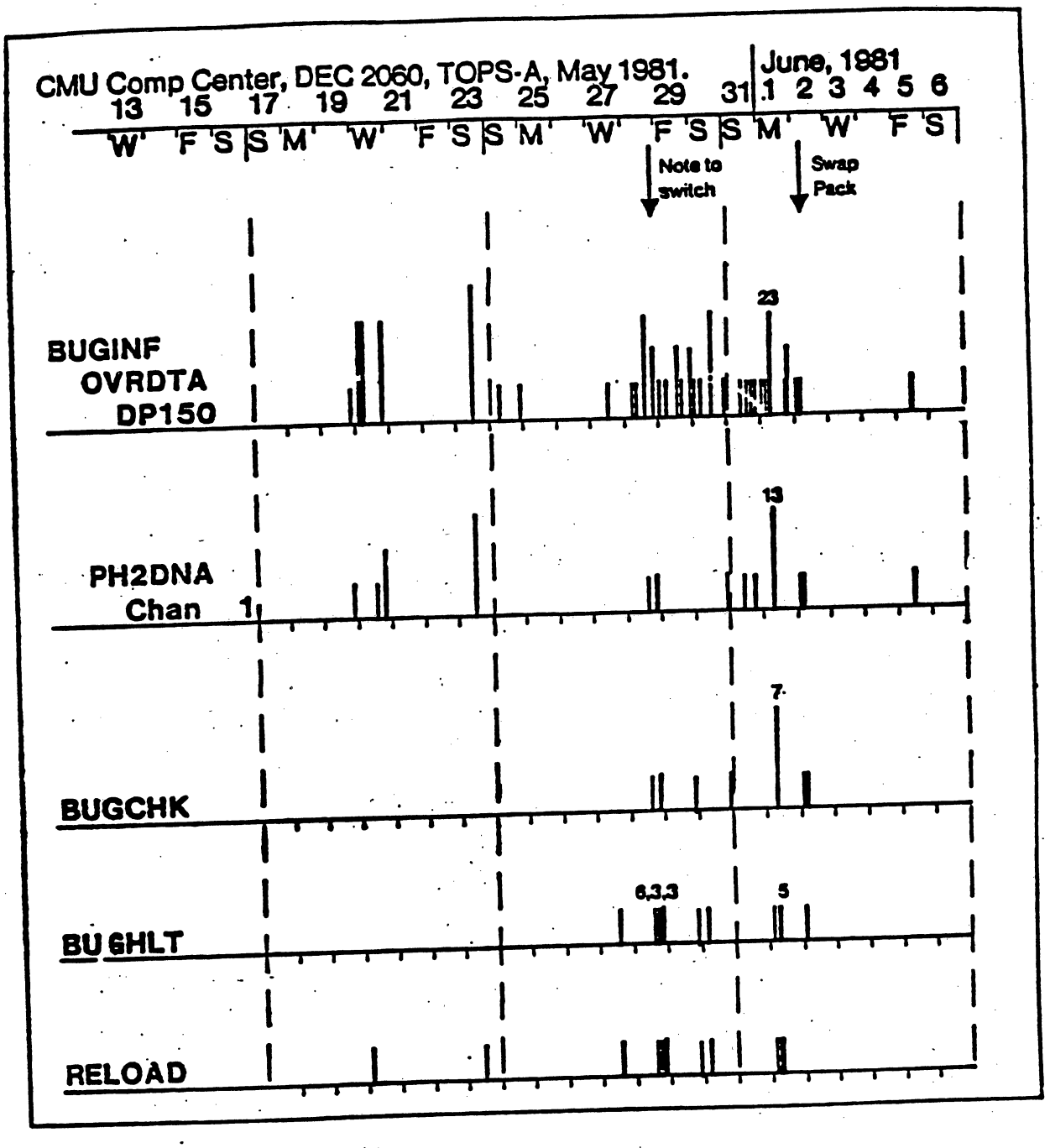
Finding Patterns

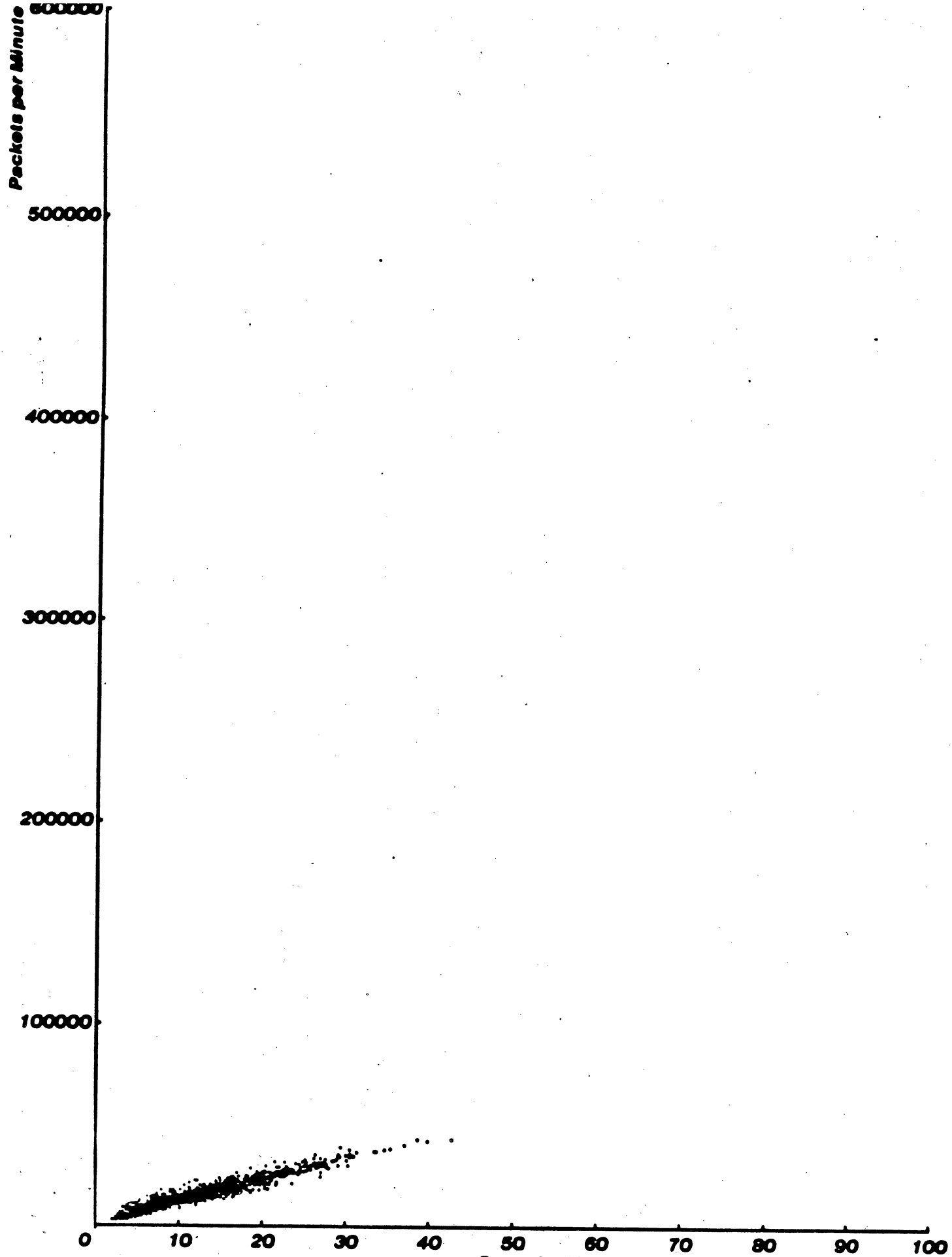
- Syntatic feature
- Semantic features
- Temporal features

Trend Analysis

Clustering

Manually Derived Trend Analysis
- RP06 on TOPS-A.



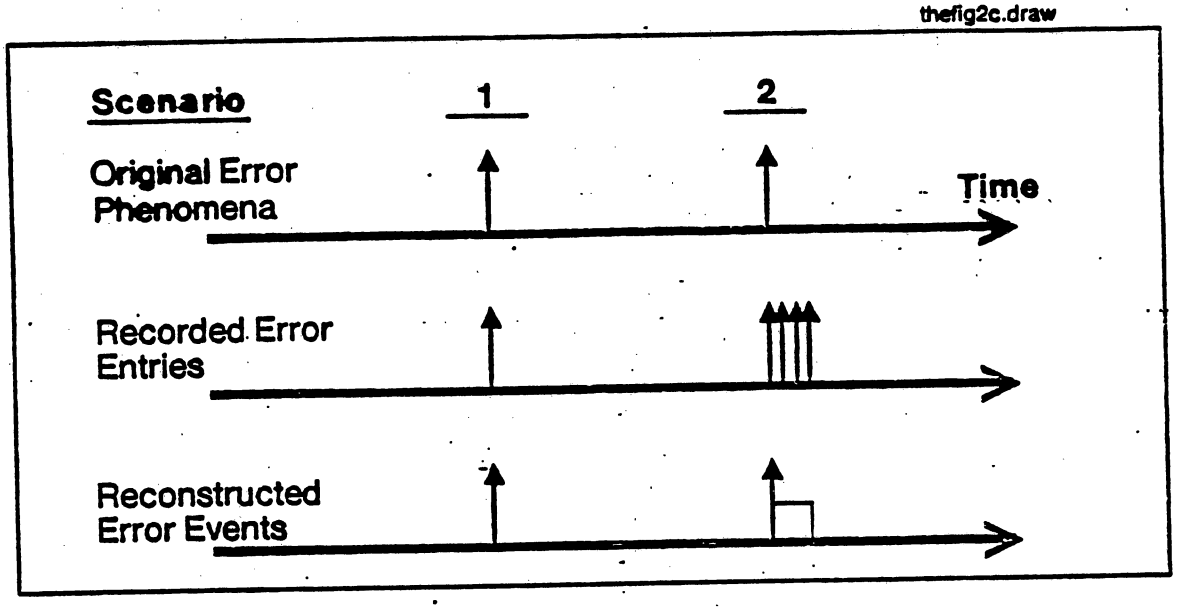


Ethernet Load vs Packets Over 24 Hours: CS Ethernet Spine - Date : 2-OCT-86

Example of a System Error File

```
SEQ    TIME    Sat 23 May 81
-------------------------------------------------------------------------------
11. 10:28:57 LP20 STD STAT=146 GEN STAT=0
-------------------------------------------------------------------------------
12. 11:07:03 DL11C CONFIGURATION REPORT
13. 11:07:03 DH11 CONFIGURATION REPORT
14. 11:07:03 LP20 CONFIGURATION REPORT
15. 11:07:04 CD20 CONFIGURATION REPORT
16. 11:07:04 DM11BB CONFIGURATION REPORT
17. 11:07:04 DL11C CONFIGURATION REPORT
18. 11:07:04 DH11 CONFIGURATION REPORT
19. 11:07:04 LP20 CONFIGURATION REPORT
20. 11:07:04 CD20 CONFIGURATION REPORT
21. 11:07:04 DM11BB CONFIGURATION REPORT
22. 11:07:04 RELOAD OF Carnegie-Mellon University TOPS-A, TOPS-20
                    Monitor 4(3354)-2 VERSION 4(3354)-2
                    BUILT ON Mon 27 Apr 81 13:44:42 REASON PS BROKEN
-------------------------------------------------------------------------------
23. 11:18:38 DL11C CONFIGURATION REPORT
24. 11:18:38 DH11 CONFIGURATION REPORT
25. 11:18:39 LP20 CONFIGURATION REPORT
26. 11:18:39 CD20 CONFIGURATION REPORT
27. 11:18:39 DM11BB CONFIGURATION REPORT
28. 11:18:39 DL11C CONFIGURATION REPORT
29. 11:18:39 DH11 CONFIGURATION REPORT
30. 11:18:39 LP20 CONFIGURATION REPORT
31. 11:18:40 CD20 CONFIGURATION REPORT
32. 11:18:40 DM11BB CONFIGURATION REPORT
33. 11:18:40 RELOAD OF Carnegie-Mellon University TOPS-A, TOPS-20
                    Monitor 4(3354)-2 VERSION 4(3354)-2
                    BUILT ON Mon 27 Apr 81 13:44:42 REASON SUBSYS BROKEN
34. 11:18:40 BUGCHK DIRFDB AT Sat 23 May 81 11:16:59 USER OPERATOR
                    CONI APR= 7740,3 CONI PAG= 0,660123 ERA= 202000,5714
35. 11:18:43 BUGCHK DIRFDB AT Sat 23 May 81 11:16:59 USER OPERATOR
                    CONI APR= 7740,3 CONI PAG= 0,660123 ERA= 202000,5714
36. 11:19:20 NCU STARTED PROGRAM: NETCON VER:4(25)-2
                    STARTED ON NODE TOPSANETCON
-------------------------------------------------------------------------------
37. 11:23:23 DOWN-LINE LOAD OF NODE DN20A BY NODE TOPSA
                    LINE DESIGNATION DTE20_1_0
                    FILE LOADED PS:<SUBSYS>DN20A.SYS.12
38. 11:24:36 DETACH TU72 S/N:21287 AS MTA0 AT CHANNEL #3 CONTROLLER #0
                    UNIT #0 REASON: Xero xrun
-------------------------------------------------------------------------------
```

Deducing Original Events



Related Concepts

Error Record or Error Entry

Each reported error is entered into the system error file.

Clustering Algorithm

The heuristics used to group or coalesce error records in a system error file into logical groupings.

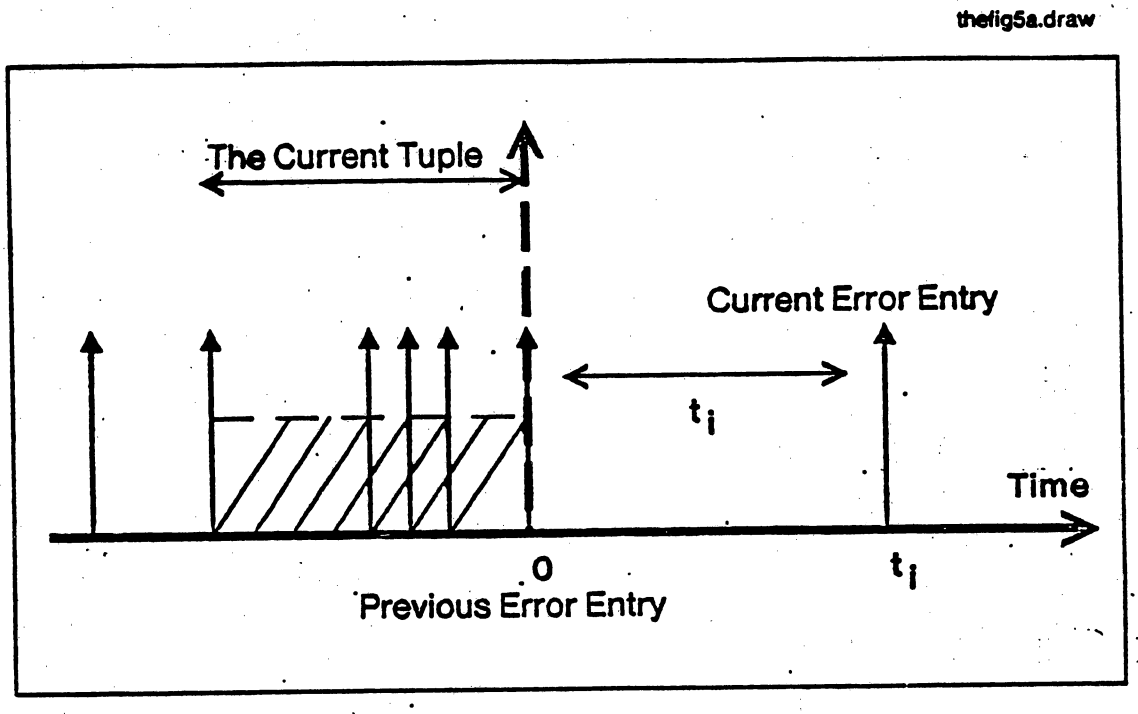
Attributes of a Tuple

Parameters that describe a Tuple.

Hierarchy of Attributes

The attributes can be organized into a hierarchy.

Tuple Clustering Algorithms



VALIDITY OF TUPLE ALGORITHMS

330 Machine-days - - - - - 58,305 Entries

Two Procedures

- Cluster time = 2.8 minutes
- Cluster time = 22.5 minutes
- No physical location information
- Same entry type as any current entry

TUPLE RESULTS

95% attributable to procedure 1

Factor of 20 reduction

- 58,305 entries ---> 3,050 entries
- 55,245 entries ---> 2,452 tuples

Five categories of tuple types

- Normal status reports
- Normal (soft) device errors
- Recoverable system crashes
- Known hard failures
- Unidentified

Categories of Tuple Types

1. **Normal operational status report** entries.
   (Such as Seq. 11.)

2. **Normal device errors**, usually self recovered, nuisance entries.
   (Seq. 38, detaching tape drives.)

3. **Recoverable system crash**, a major interruption of system service, but usually recoverable.
   (Seq. 12 to 22, Seq. 23 to 36.)

4. **Known hard failure symptom**, be it soft*w*are or hardware caused.
   (Such as the OVRDTA and PH2DNA pair.)

5. **Totally unexpected**, or of such a rarity, that only a few engineers know about it.

TUPLE EXTRACTION

Concept of Tuples

Hierarchy of Attributes

- Starting time
- Spanning time
- Unique entries

- Event type sequence and latency
- Number of events of particular type

- Physical device location
- Logical structure
- Serial number
- Address

- Device error registers

MATCHING

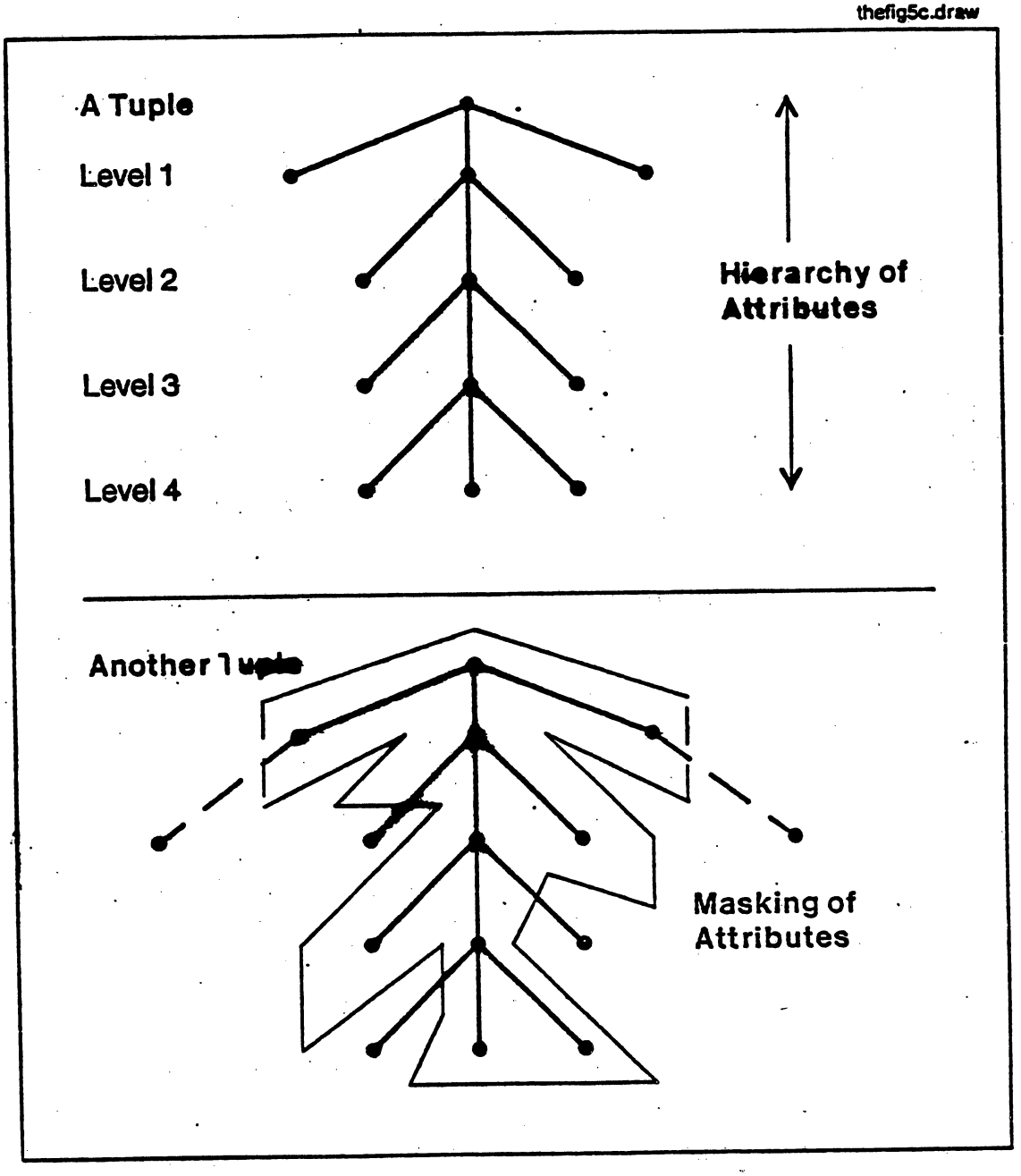
Determine uniqueness of a tuple.

Matching techniques, increasing rigor.

- Time
  - Spanning time
  - Entry count
  - Tuple degree size
- Entry type
  - Entry count
- Device specific information
  - Logical structure
  - Serial number
  - Address
- Error registers
- Individual error bits

Tuple Types

and Matching Algorithms



MATCHING RESULTS

Factor of 10 decrease in information

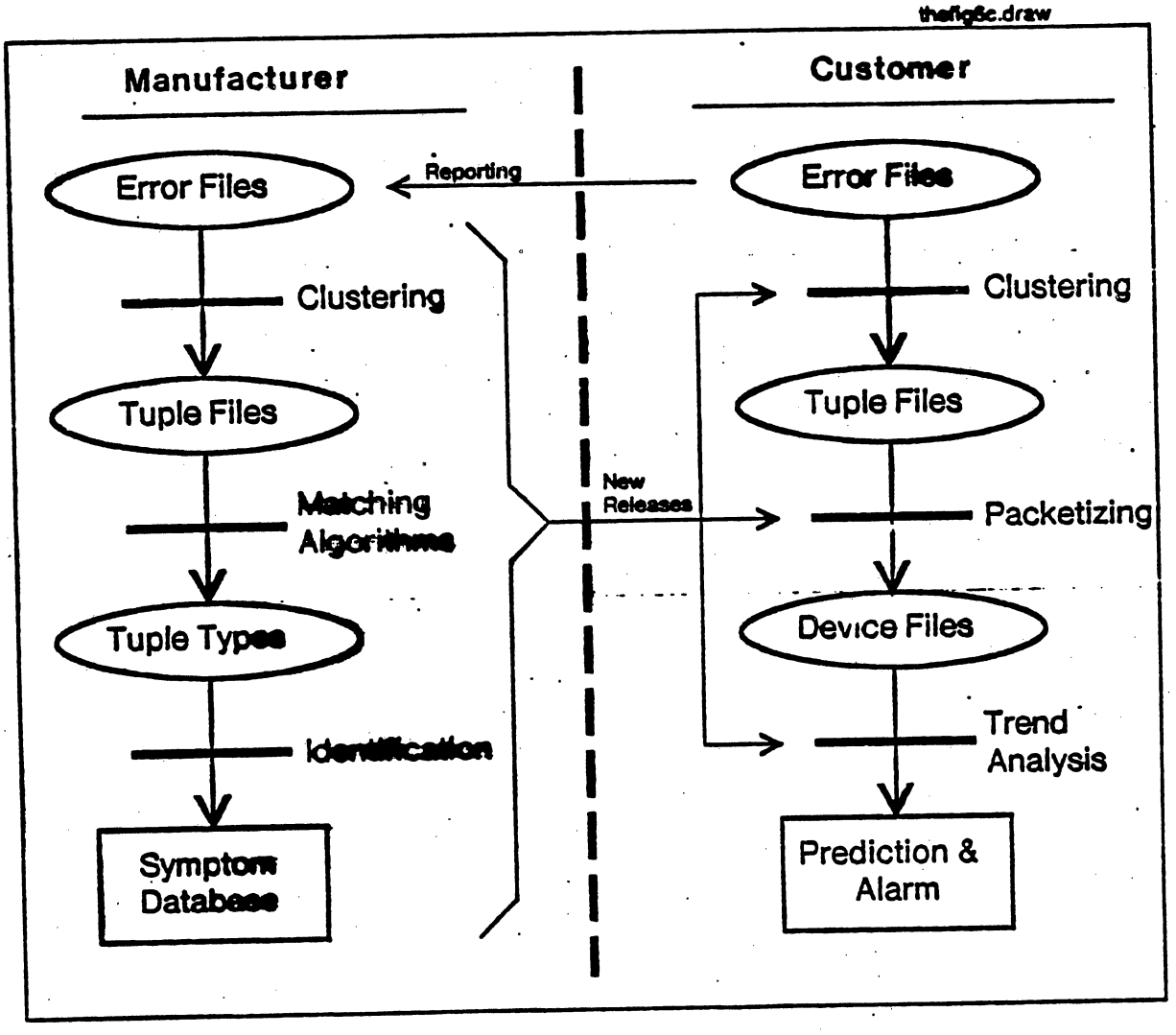
2,452 tuples ---> 255 types

4 types = 65.2%

75% of unique types in 15% of observation period

Reduce system event log from 200 ---> 2

Application of the Tuple Concept



System Specification

DESIGN FOR SYSTEM RELIABILITY

7 System Specifications

OBJECTIVES

* Translating reliability requirements into system specifications

USING FIELD SERVICE LCBM

MAKING BUSINESS TRADEOFFS FOR RELIABILITY

MTBPR : MEAN-TIME-BETWEEN-PARTS-REPLACEMENT

F.S. BUSINESS PLAN GOAL = 2000 HRS

CPU LOGIC MODULES

USING MIL217D - LAMBDA

PREDICTING THE IN-FIELD RELIABILITY

ASSUMES MATURE ENGINEERING/MANUFACTURING

REVIEWING RELIABILITY "LEVERS"

CALCULATING RELIABILITY IMPACT OF DESIGN CHANGES

DOES NOT DIRECTLY PREDICT INTERMITTENT/TRANSIENT RATES

0 TECHNOLOGY SELECTION

LSI VERSUS MSI

LSI: 3 - 10 TIMES AS RELIABLE AS MSI

VENDOR RELIABILITY ESTIMATES (SPECS)

VENDORS SHOULD BEAT MIL217D VALUES

	MIL	VEND
ECL LSI	.53	.36
ECL MSI	.022	.012
ECL RAM	.25	.06

AVERAGE FAILURE RATE PER MILLION HOURS

0 VENDOR SCREENING SELECTION

"STRESS SCREENING"

"PRECONDITIONING"

"BURNED-IN"

EARLY DETECTION OF PATENT/LATENT DEFECTS

DETECTION OF "MAVERICK" LOTS

COMMERCIAL "HI-REL" PARTS

100% THERMAL CYCLE

100% BURN-IN

100% HI/LOW TEMP TESTING

10¢/part
factor of
2-4 better

- TECHNOLOGY QUALIFICATION
  - DEFINED IN PURCHASE SPECIFICATION
    - USUALLY REFERENCING MIL883 METHODOLOGY
  - DETAILED FAILURE DATA ON CHOSEN TECHNOLOGY(S)
  - INITIAL VERIFICATION OF COMPONENT RELIABILITY
  - POSSIBILITY FOR PERIODIC REQUA_'S

- JUNCTION TEMPERATURE REDUCTION

$T_J = T_{AMB} + (P_{WATTS} \times R_{DA})$

FOR A 10 DEGREE INCREASE IN MCA JUNCTION TEMP:

44% INCREASE IN FAILURE RATE - VENDOR

32% INCREASE IN FAILURE RATE - MIL217D

THERMAL RESISTANCE (R_{DA}) IMPROVEMENTS

CERAMIC PARTS

HEAT SINKS

AIR FLOW

"SYSTEM" LEVEL THERMAL ANALYSIS - THUDS

R-

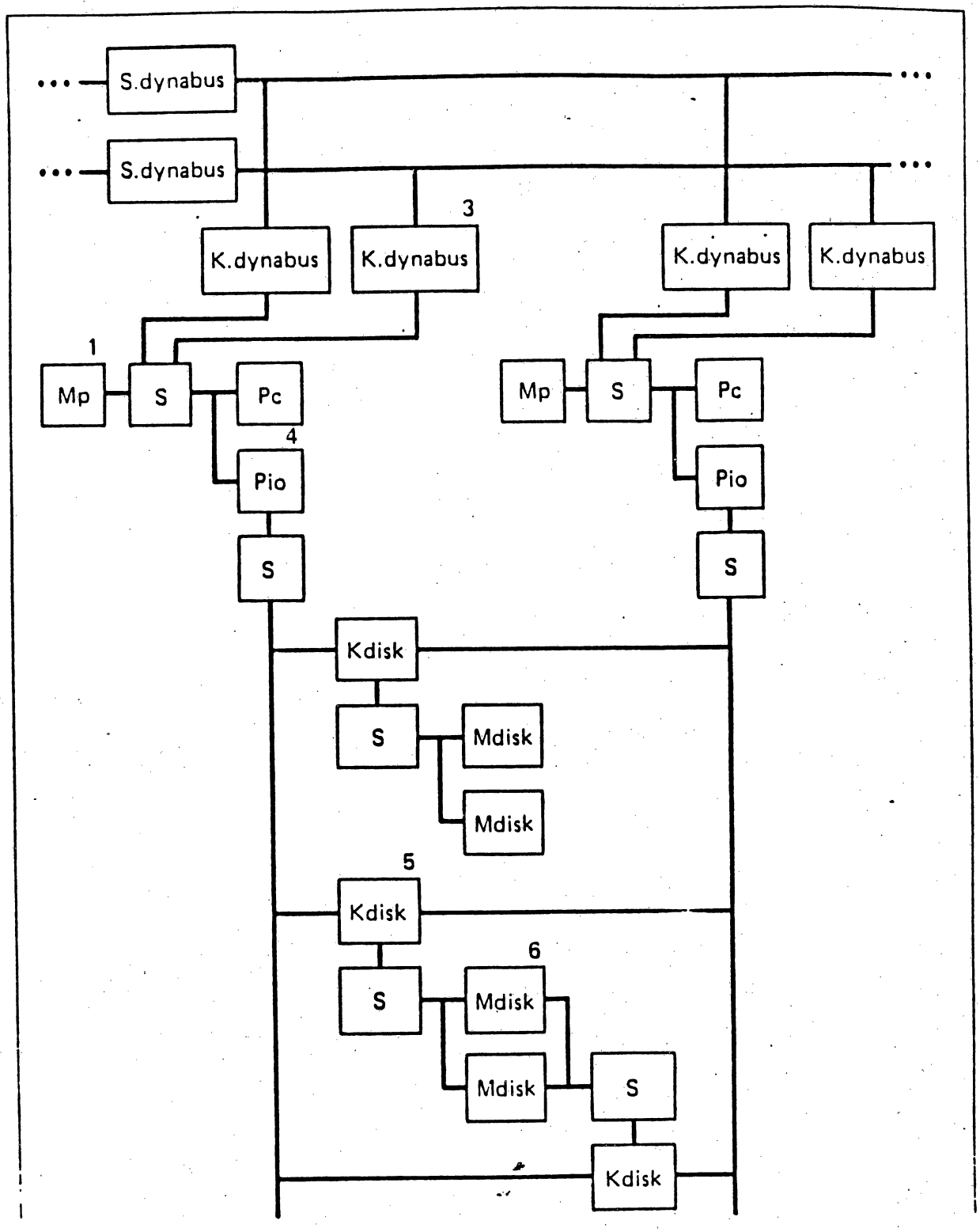
CONCLUSION

CPU LOGIC CONFIGURATION

F.S. MINIMUM ACCEPTABLE GOAL	=	2000 HRS.
SPECIFICATION/PREDICTION	=	2726 HRS.
FINAL RQT RESULTS	=	3500 HRS. @90%

TANDEM
DESIGN OBJECTIVES

- "Nonstop" operation where failures detected, components configured out of service, repaired components configured back in without stopping other system components.
- No single hardware failure can compromise data integrity of the system.
- Modular system expansion through adding more processing power, memory, and peripherals without impacting application software.


S.dynabus
S.dynabus
3
K.dynabus
K.dynabus
K.dynabus
K.dynabus
1
Mp
S
Pc
4
Pio
S
Mp
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S
Mdisk
Mdisk
S
Kdisk

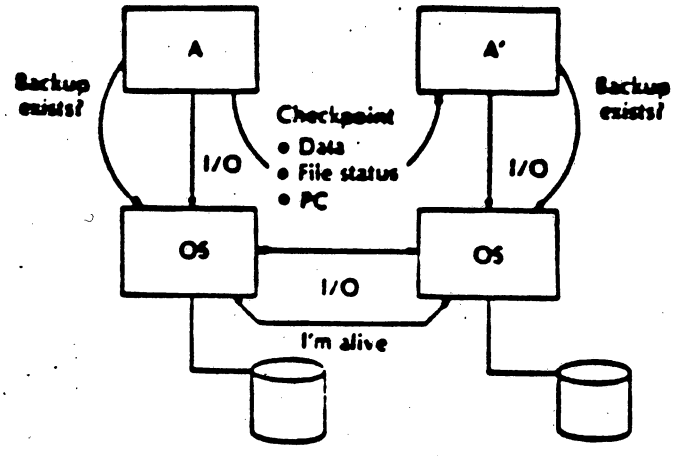


Figure II–1. Shadow processor in Tandem.

Fault Containment

- Software processes do not share state - only message passing
- Hardware - no shared memory, dual porting I/O, multiple power supply

Fast-Fail Modules (detection)

- Software - Consistency checks, defensive programming
- Hardware - software generated status probes, hardware self-tests

Software Bugs

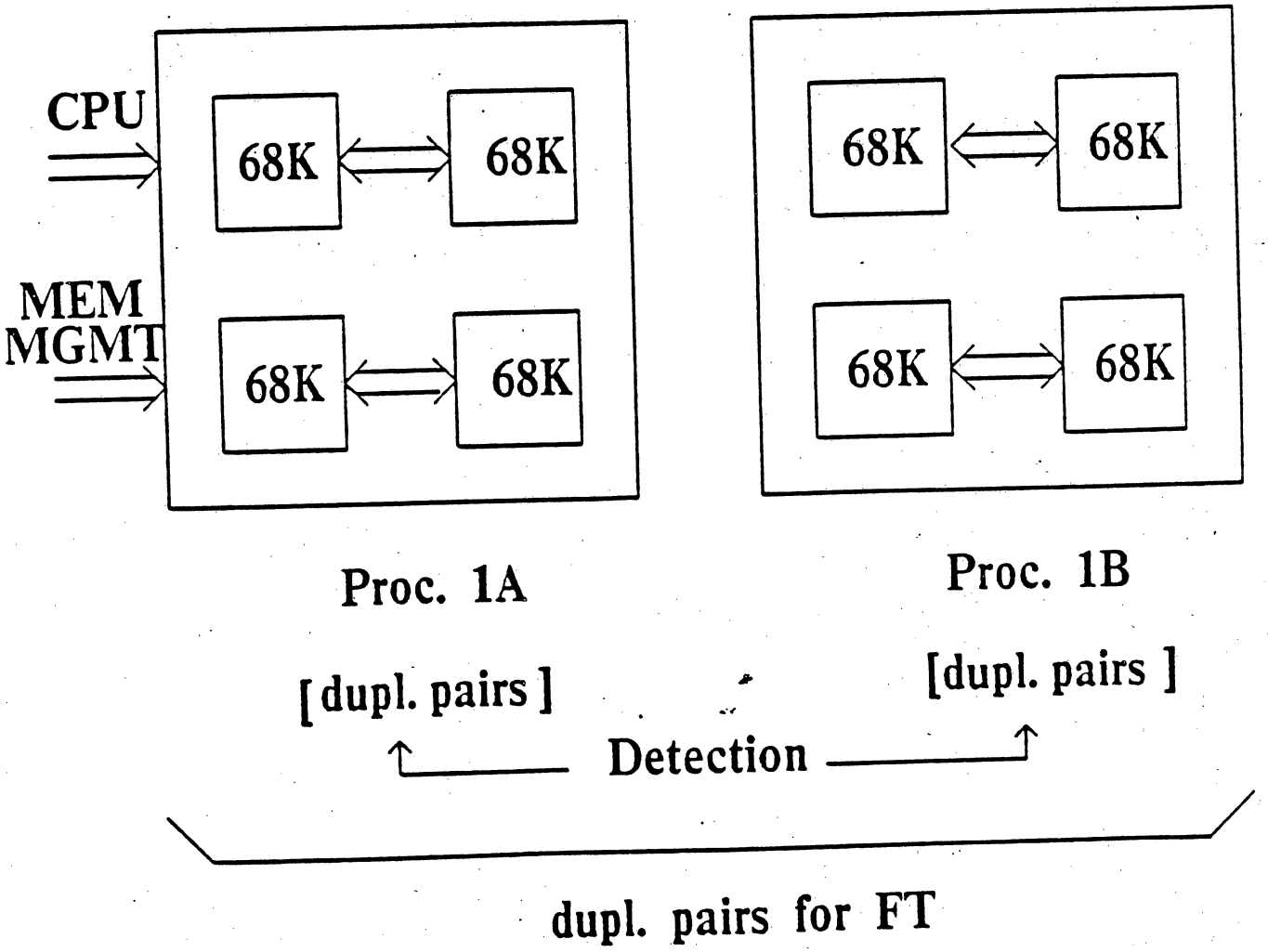
- Backup process does not encounter same state and environment; code takes a different path

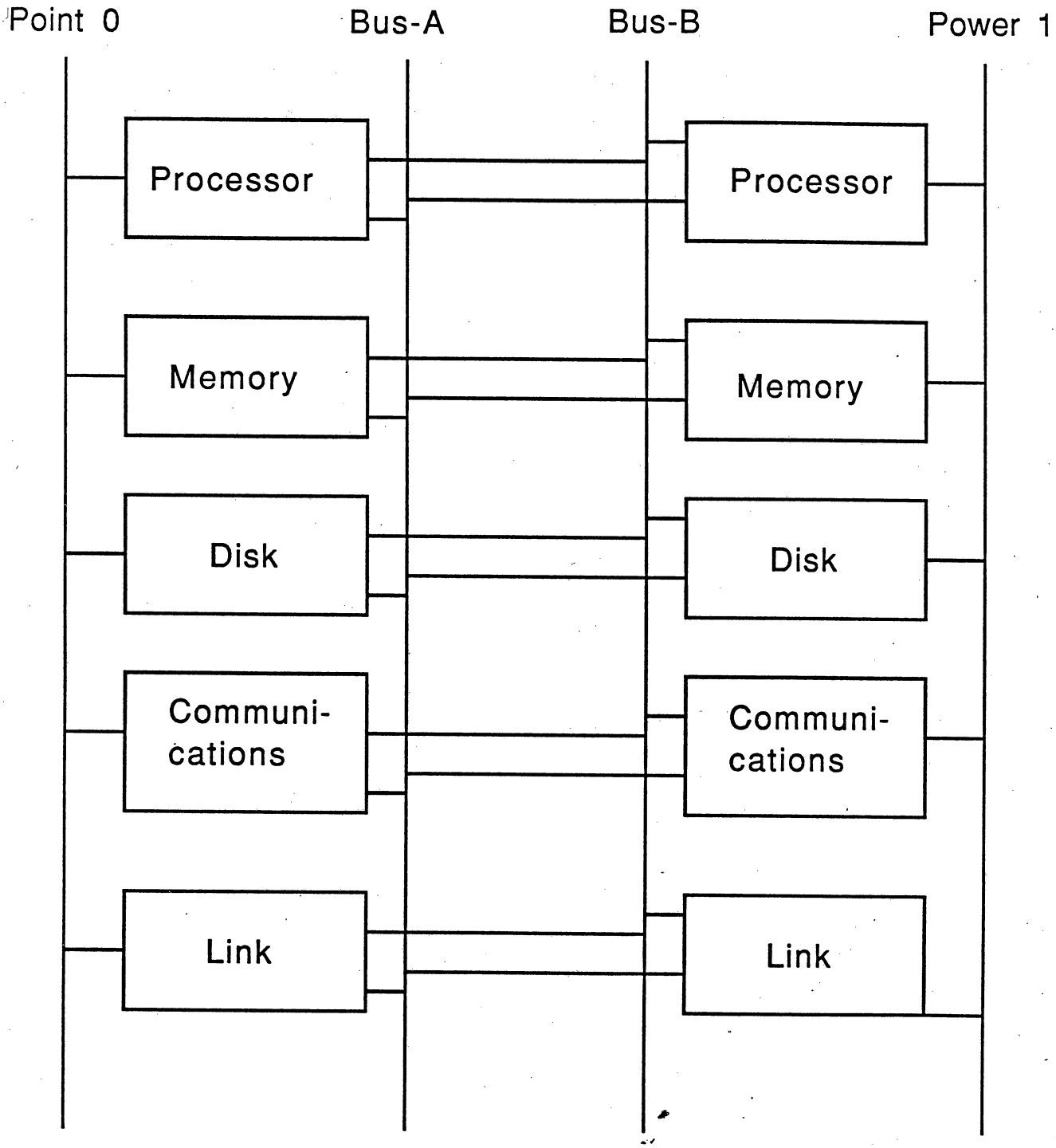
Software

- Process pairs
- Transaction processing - two phase commit protocol
- Log write - ahead protocol - record before and after - image of database in an audit trail
- Network Systems Management - programmed operators help reduce administrative errors
- Tandem Maintenance and Diagnostic System - analyze event loss to successfully call out FRU 90% of time

STRATUS /32

- Double Duplication
  - both for fault tolerance and fault detection
- Wind up having 8 68000's per FT processor in multi-pc. configuration.




Point 0
Bus-A
Bus-B
Power 1
Processor
Processor
Memory
Memory
Disk
Disk
Communi-
cations
Communi-
cations
Link
Link

FAULT TOLERANT DESIGN METHODOLOGY AND EXAMPLE:

The Intel 432

A Methodology

- Define Objectives
- Limit the Scope
- Define Confinement Regions
- Design Error Handling Mechanisms
- Design Error Reporting Mechanisms
- Testing of Error Handling/Reporting Mechanisms
- Evaluate Design

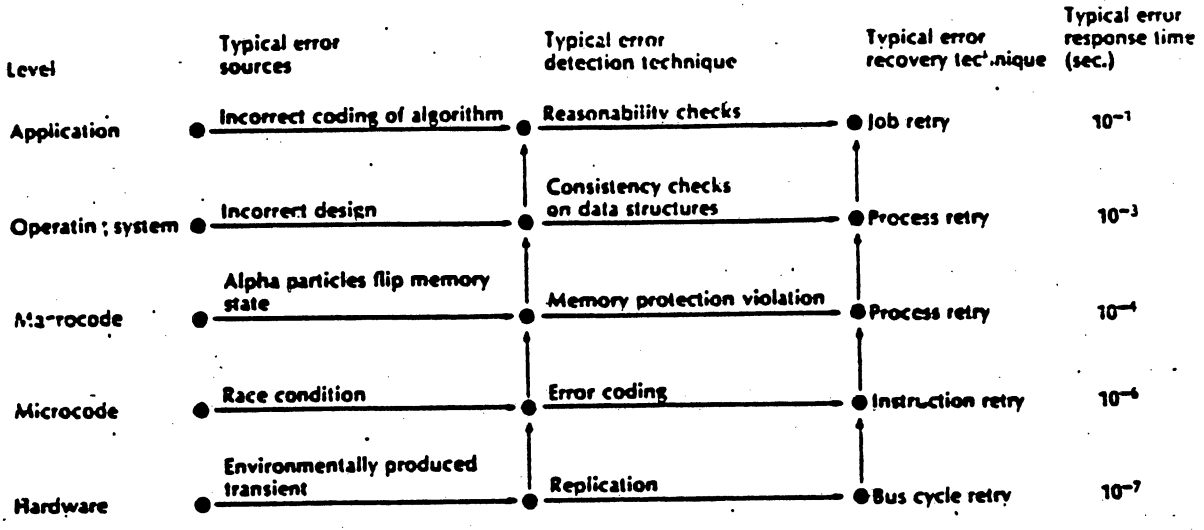


Figure 18–2. Levels in a hypothetical system.

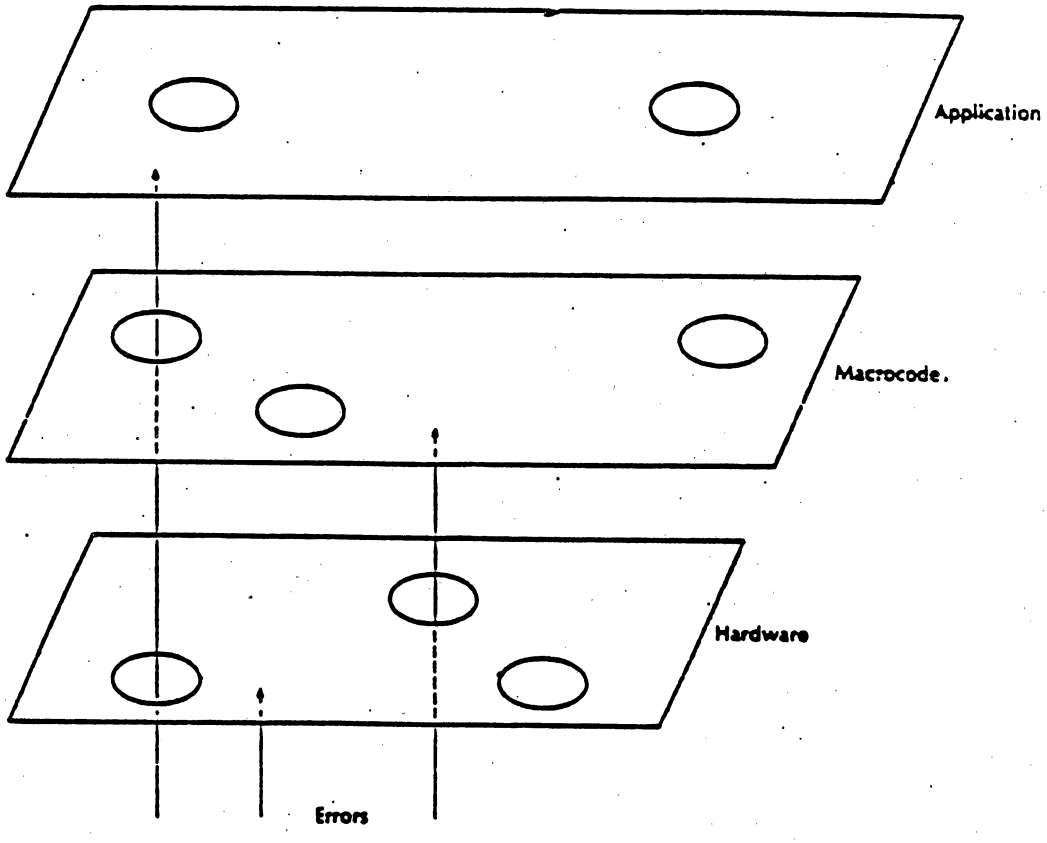


Figure 18–3. Interception of errors at multiple system levels due to imperfect coverage.

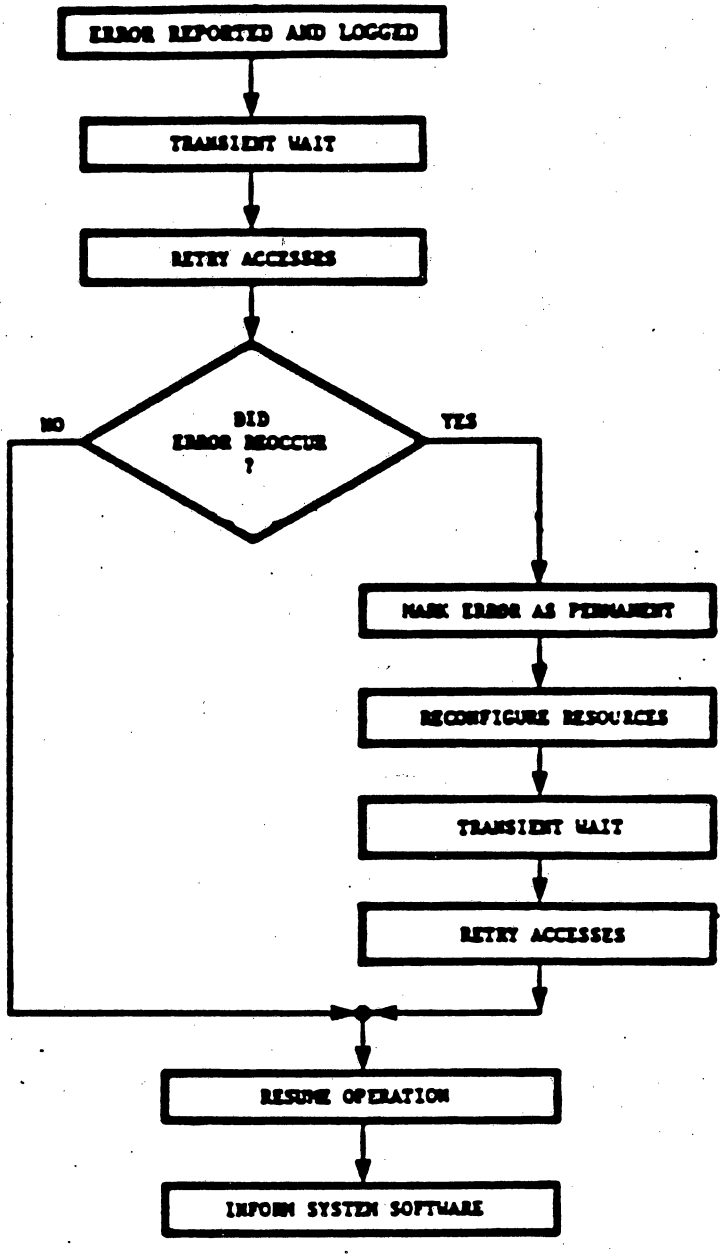


Figure 4-9. High-Level Recovery Sequence

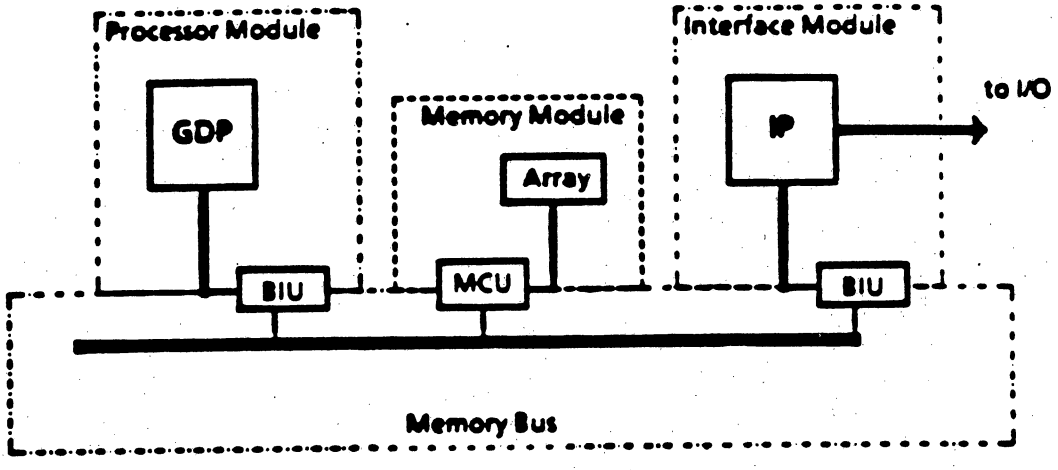


Figure 1-3. iAPX 432 Confinement Areas

F-0400

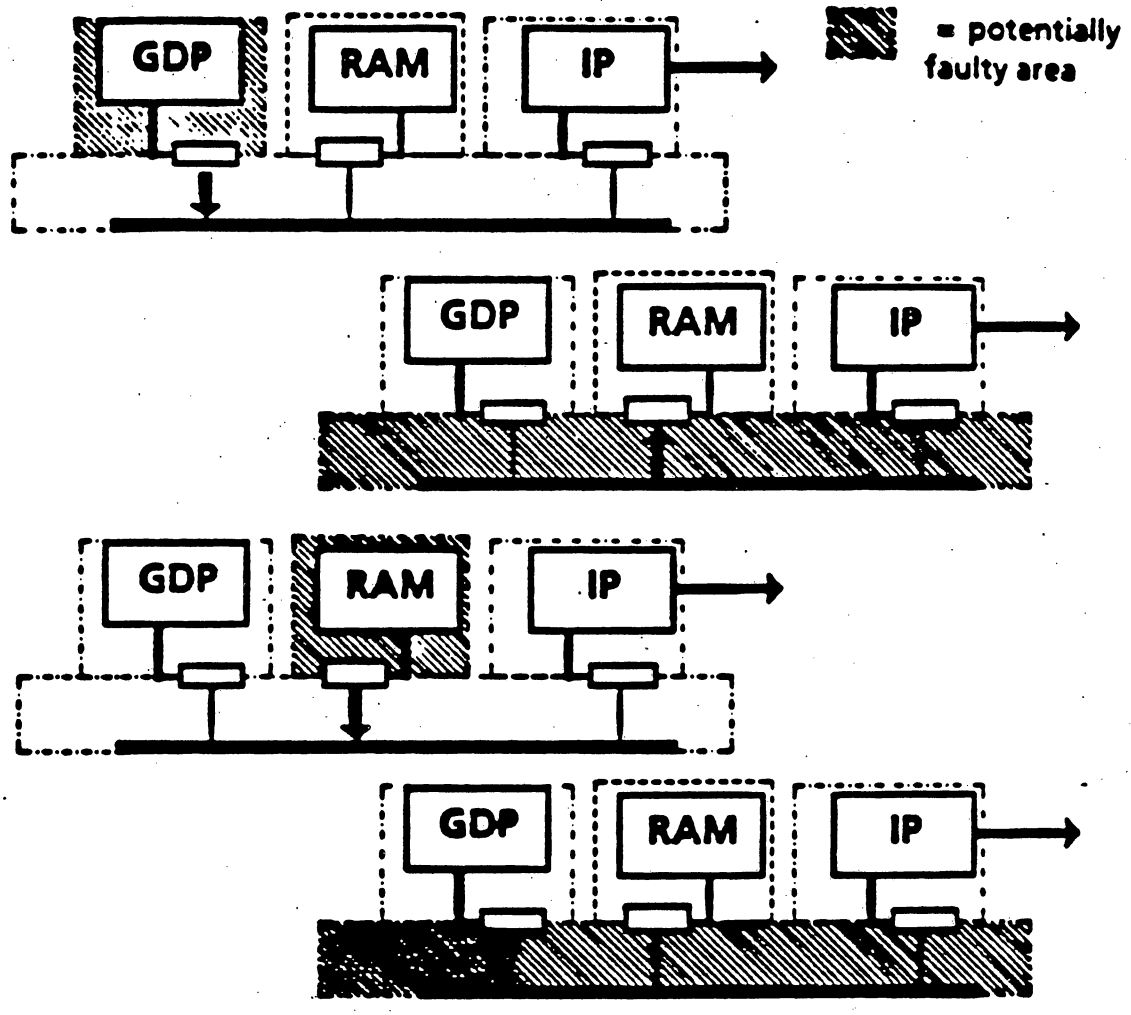


Figure 1-5. Confinement Area Operation

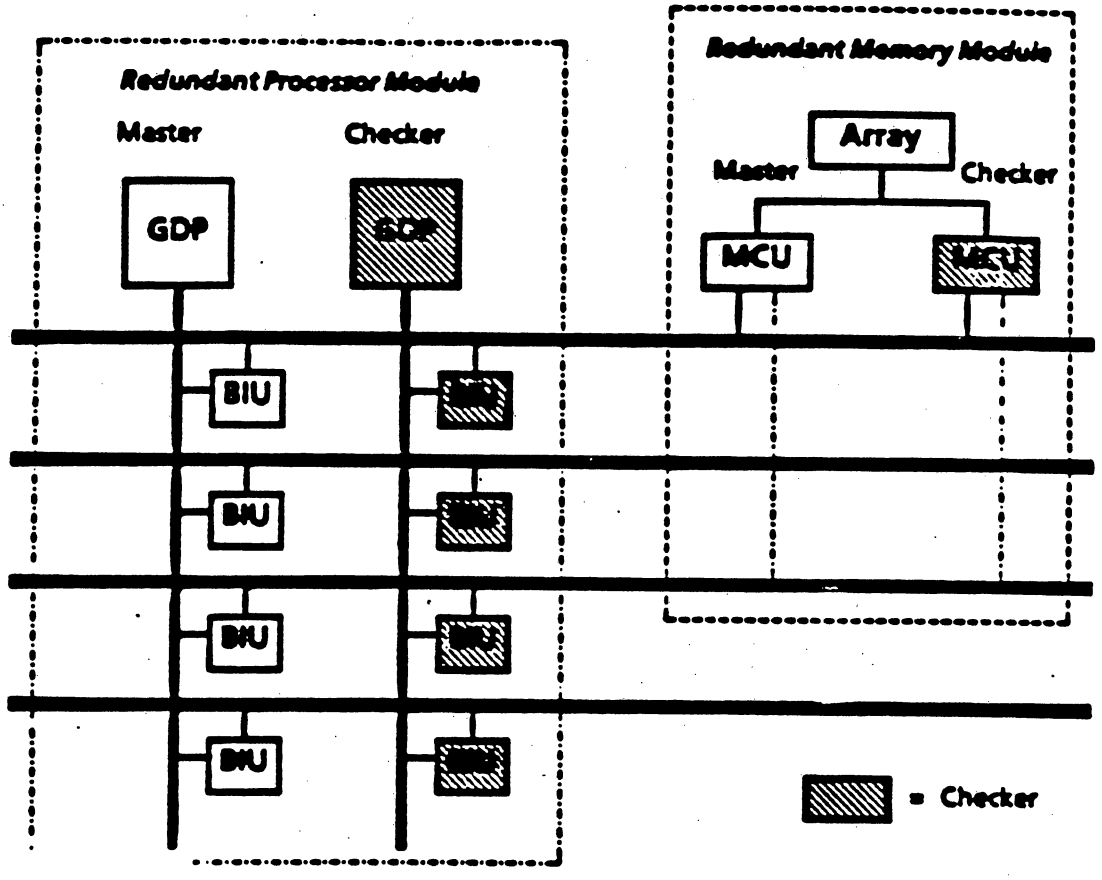


Figure 1-4. FRC Configuration Pairing

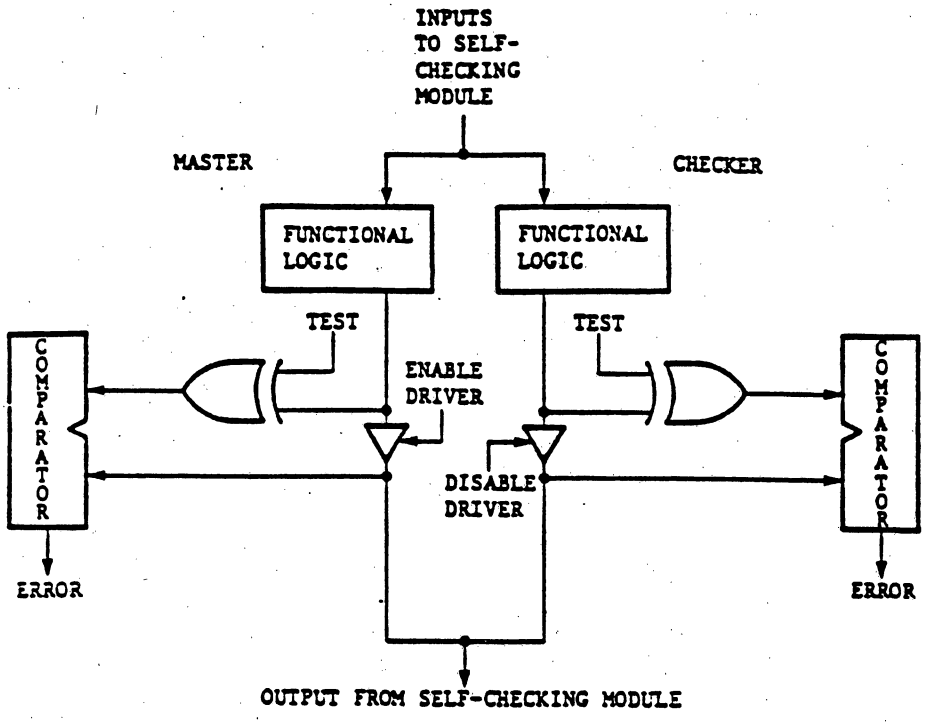


Figure 4-2. Functional Redundancy Checking

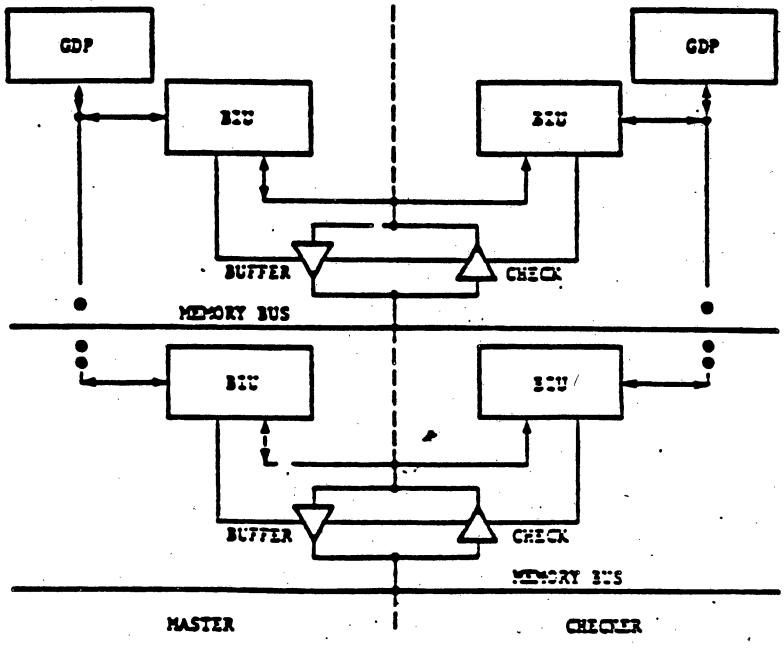


Figure 4-3. GDP Confinement Area

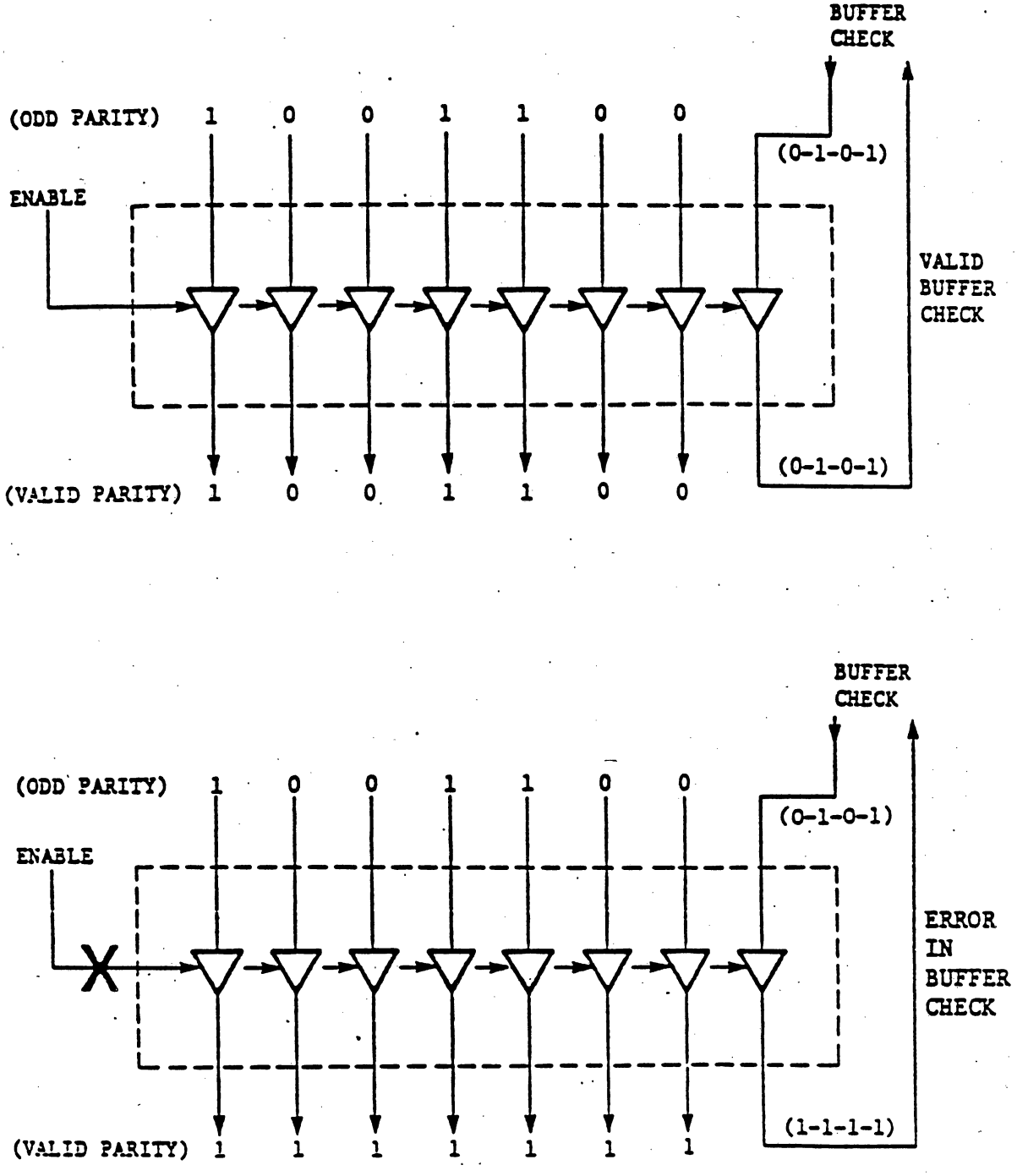


Figure 4-1. Buffer Check Detection Mechanism

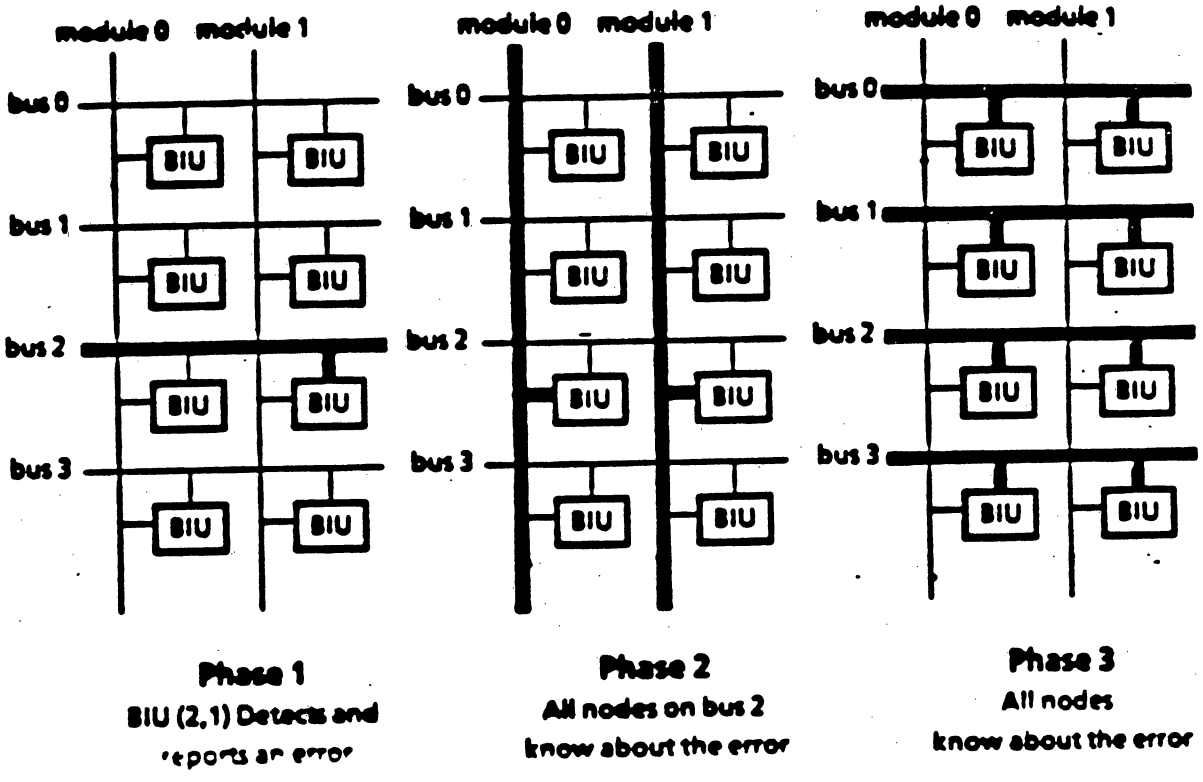


Figure 1-6. Three-Phase Error Reporting Mechanism

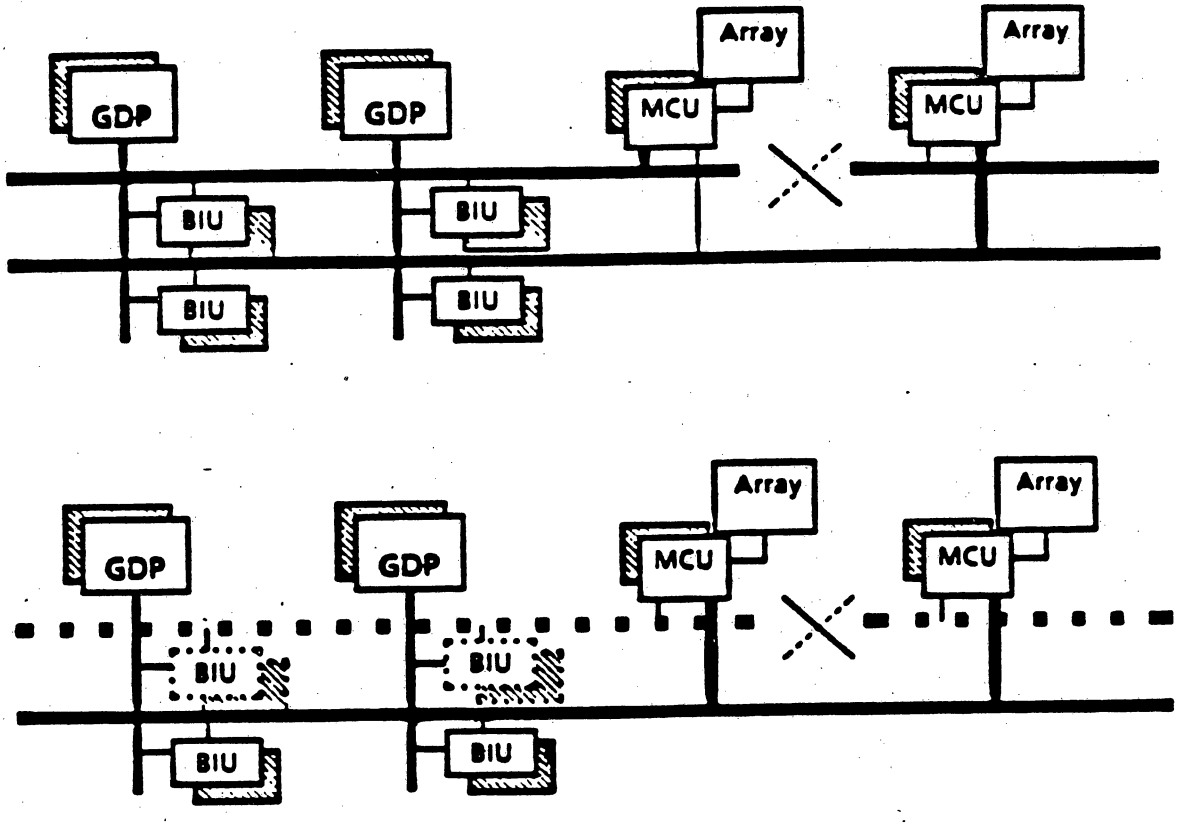


Figure 1-8. Bus Reconfiguration

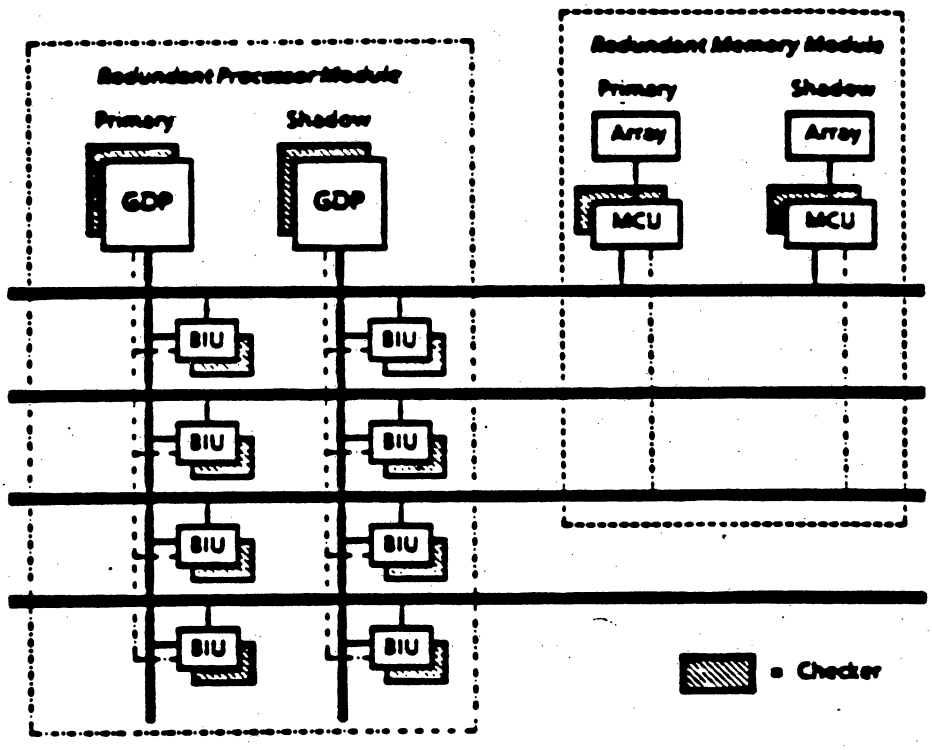


Figure 1-7. CMA Configuration Pairing

Table 1-2. Exercising Latent Faults

DORMANT AREA	EXERCISE
Memory Locations	MCU periodically reads every array location (scrubbing).
Detection Mechanisms	Software[a] periodically forces error conditions into the detection mechanisms.
Reporting Mechanisms	Software[a] periodically initiates and observes error reports.
Recovery Mechanisms	Software[a] periodically invokes recovery operations.

[a]Special commands to support exercising dormant areas are provided in BIUs and MCUs.

Table 1-1. Recovery Mechanisms and Coverage

MECHANISM	COVERAGE
Retry	Transient Errors
ECC	Storage Array Address and Data
Spare Bit	DRAM Replacement
Memory Bus Pairs	Memory Bus Failure
Module Shadowing	Module Failure, GDP, IP, or Memory

Conclusion

- Designing from first principles to produce an architecture to tolerate failures achieves better reliability, availability, and cost effectiveness than an ad hoc, add-on approach.
- It is possible to build systems in which the activities of fault detection, diagnosis, and recovery are completely automated and transparent to the user.

Appendix

Questions to Ask and Rules of Thumb

D. Siewiorek

rev. Jan 1988

1. Reliability is Important.

It makes sales, and profits. Many customers are prepared to have a known high up-front cost rather than a low total cost of ownership.

- **Trade-offs can be formulated.** Cost of ownership - Cost = Initial Cost + 7.86 lambda, lambda in Failures per million hours.
- **Customer unhappiness can be anticipated and prevented.** "Symptom directed diagnosis" uses event logs to help isolate problems. Automatic information reduction and analysis can improve the effectiveness of information representation to field service personnel. SPEAR is an effective, evolving tool. "Symptom" data should be collected starting with PMT.
- **Be clear about the goals.** Goals determine system design philosophy - reliability or availability, grain of correct data output and loss of data, transparency to user, dedicated or general purpose, new design or add-on.
- **Customers call many different things "reliability", watch it.**
- **Get started with what you have and iterate; don't stall!** Design decisions have to be made based on the best available data including modeling, predictions, and data from previous products. There is never enough data - don't wait for detailed answers to justify inclusion of a RAMP feature.
- **You have to want it.** The major ingredient in achieving quality is setting a goal. Aggressive goals are required to improve quality. These goals should include MTTF and Mean Time to Crash (MTTC). Financial models and qualification tests should take MTTC into account.

2. Reliability is Possible.

The competition is achieving it; it doesn't happen by itself. It doesn't require inspiration, just planning and hard work.

- Possible to build systems on order of magnitude or two better than today - Tandem is doing it.
- **One set of design rules are:**
  - detects errors early - limit damage
  - correct at lowest possible level - limit recovery
  - complexity
- **What kind of problems are actually happening?** Transients 20-50 times more frequent than permanent faults - so pay attention.
- **Some techniques are questionable - verify when possible.** Accelerated life testing
  - what activation energy
  - what is the acceleration factor
  - ambient temperature test for sanity check.
- Designing from first principles to produce an architecture to tolerate failures achieves better reliability, availability, and cost-effectiveness than an ad hoc, add-on approach. It is possible to build systems in which the activities of fault detection, diagnosis, and recovery are completely automated and transparent to the user.
- Good ways and bad - patch, patch, patch is disaster.

- There is a rich array of fault avoidance, fault detection, fault masking, and dynamic redundancy techniques. Designers can index into a catalog of techniques using cost, reliability, and portion of system being designed. (Steve Elkind's chapter 3.)
- Fault avoidance techniques including cooling, screening, better thermal constants, and use of large scale integration, can have a large impact on reliability
- Coding theory provides a rich set of techniques including parity, check sum, M-of-N, arithmetic, residue, cyclic, hamming, and block codes. It is very cost-effective.
- Improving coverage is more important than improving MTTF.
- Reliability modeling is an on-going process starting with product goal setting and successively refined through field deployment as better data becomes available.
- A methodology for reliable design: define objectives, limit scope, define confinement regions design error handling mechanisms, test error handling reporting mechanisms, evaluate design. Intel used this. Close to phase Review process.
- **Not a one-shot effort.** Reliability and quality need to be part of the specification and design process - starting early and continuing throughout product development and life. A reliability/quality team can provide guidance but the design engineers have the most impact since they are intimately familiar with design trade-offs and opportunities.
- **High rates of improvement are reasonable.** IBM's goal is to double MTTF every two years for the next decade.
- **Learn and improve.** Use and analyze error logs starting with DMT to characterize behavior. Pay attention to all errors. In retrospect, traces of problems in the field have been found in the pre-shipment qualification process.

3. **Reliability is Non-Trivial.**
   - It demands expertise; have good people available for your projects/products. Carelessness or amateurism can be fatal.
   - Qualification process team to monitor entire qualification process including: product assurance, reliability, design, manufacturing, and maintainability. If you are on a product and don't see all the members here, ask where they are.
   - **Be clear about levels and stages.** Framework - what physical level in a system?

     - what stage in the life of a system?]

     Use the right models. Check that the are right. Permanent faults follow exponential distribution. Transient faults follow Weibull distribution.
     - which are you using, large potential error if assume exponential and it's actually Weibull?
   - **Classical models may be oversimplified.** A large gap between classical stuck-at faults and system level manifestations.
   - **Some common formulas have hidden assumptions. Check.** MTTR = 1/failure rate, only for nonredundant systems, modeled by exponential.
   - 10 degrees C increase in junction temperature decreases MTTF by a factor of 2. IBM's maximum junction temperature goal is 85 degrees C. DEC's goal is 100 degrees C.
   - Many different reliability metrics. Many different reliability models. Understand the assumptions and limitations of the models.
   - Financial models, feature failure-mode matrix, life-cycle cost models, and profit sensitivity models can help make design decision.

4. **Reliability is a System Problem.**

The word "system" means lots of different things; and almost all of them apply here.

- Decisions on RAMP should be made globally. For example, even though LSSD can be justified based just on decreased testing effort and increased test coverage, diagnostic engineering may not be able to make the decision alone. However, once LSSD latches are included, it is very cost-effective to add error detectors and retry (i.e., data from the previous cycle is captured in the LSSD latch).
- **Some models for software are possible.** Software reliability models are similar to models of hardware design errors at specification stage.
- **Separate models can be tied together.** Can use Markov model to tie together usage of separate software models.
- New systems models - which include both hardware and software being developed relating workload to reliability.
- All models presented in the course (except Mil217) can be used for modeling hardware, software, or systems.
- Diagnosis is vital. Only 5% of the service calls can consume over 35% of the repaid labor hours. Use design for testability and maintainability to remove the "tail of the dragon." Time to diagnose faults in manufacturing increasing with module complexity.
- **You need good components, how do you get them cheaply?** Rule-of-ten in testing costs. Finding a faulty component increases in costs by a factor of ten for each successive level in the hierarchy (chip, board, system, field).
- Designing from first principles to produce an architecture to tolerate failures achieves better reliability, availability, and cost-effectiveness than an ad hoc, add-on approach. It is possible to build systems in which the activities of fault detection, diagnosis, and recovery are completely automated and transparent to the user.
- Testing is a major portion of component coast.
- Automatic test generation time grows as N exponent 3 where N is the circuit complexity. ATG fault coverage decreases with module complexity.
- Validation and verification techniques during the specification and design stages applicable to both software and hardware. Techniques include manual, proof of correctness, simulation, functional, structural. Techniques can be static or dynamic. Grading of test set quality based on coverage complexity, and seeding errors.
- Philosophy of levels and severity of recovery actions.
- Aggressive goals are required to improve quality. These goals should include MTTR and Mean Time To Crash (MTTC). Financial models and qualification tests should take MTTC into account.
- Improving quality of products requires uniform attention to details through all phases of product development and life.
- The decision to include an individual RAMP feature cannot be made in isolation. The cost and effectiveness of each feature depends on the rest of the design.

5. **Reliability is achievable in many different ways.**

- Raw testing is expensive and difficult, and is a poor solution.
- Retry is very effective against transients.
- Testing is a stimulus/response experiment. There are numerous ways to generate stimulus

and check responses.

- **Design or test pays off several ways.** Design for testability techniques can be effective in improving test coverage at a hardware cost of 5% to 20% and performance cost of 5%. DFT decreases design evaluation time by 20%, test development time by 33%, module testing time by 70%.
- Generation of diagnostic programs is taking as much effort as the actual design of contemporary systems. Design for testability can improve coverage and time to market (DFT pays off several ways);
- **Lots of techniques.** Testing approaches include: scan, controllability/observability, linear feedback shift register, fault detection, and state capture;
- Software reliability techniques equally usable on hardware design and includes: internal checks (e.g., check sums, CRC, etc.) defensive programming, retries, consistency checks on data structures, modular design, error reporting, design reviews, desk checking, peer reviews, change reviews, acceptance checking, top down design, test coverage analyzer, regression testing, assertion checking, and system modeling. Design support tools critical. In hardware you are already doing information hiding.
- Largest potential gain for improving DEC product quality is improving error detection coverage and recovery through retries. Error detection coverage (sometimes also called Built-in Self-Test) helps in prototype debugging, manufacturing, and field operation.

4P METRIC OVERVIEW:

Accronym	Metric Name
ALL K CALLS	TOTAL CLOSED CALLS
CORR REPAIRS	TOTAL CONTRACT CORRECTIVE REPAIRS
CORR REPAIRS w M	TOTAL CONTRACT CORRECTIVE REPAIRS WITH MATERIAL
ATBR (MON)	AVERAGE TIME BETWEEN REPAIRS
AMTTR	ASSIGNED MEAN TIME TO REPAIR BY OPTION TYPE
TMTTR	TOTAL MEAN TIME TO REPAIR BY OPTION TYPE
UNASS RATIO	UNASSIGNED RATIO BY OPTION TYPE
%CALLwUNASS	PERCENTAGE OF CALLS WITH UNASSIGNED LABOR BY OPTION TYPE
MDAHPMR	MEAN DIRECT ACTIVITY HOURS PER PREVENTATIVE MAINTENANCE REPAIR BY OPTION TYPE
MDAHRPR	MEAN DIRECT ACTIVITY HOURS PER REPAIR BY OPTION TYPE
MTTIAO	MEAN TIME TO INSTALL ADD-ONS BY OPTION TYPE
DOAPRC	SPARES DEAD ON ARRIVAL PERCENT BY OPTION TYPE
MEPR	MATERIAL EXPENSE PER REPAIR BY OPTION TYPE
FRUCR	FIELD REPLACEABLE UNITS PER CORRECTIVE REPAIR BY OPTION TYPE
SAMPLE#	AVERAGE NUMBER OF OPTIONS
OPTION REV	QUARTERLY CONTRACT OPTION REVENUE
MONTHLY REV	AVERAGE MONTHLY REVENUE PER CONTRACT OPTION
DL EXPENSE	CONTRACT DIRECT LABOR EXPENSE
MATL EXP	CONTRACT MATERIAL EXPENSE
INV EXP	CONTRACT INVENTORY EXPENSE
ALLOC EXP	CONTRACT ALLOCATED EXPENSE
NET MARGIN	CONTRACT NET MARGIN DOLLARS
MARGIN %	CONTRACT NET MARGIN PERCENT

OPTION: RA81

OPTION PERFORMANCE REPORT

METRIC	FY 85 / FY 86 Q3	Q4	Q1	Q2	GOAL
CORRECTIVE ACTIVITY					
o ATBR (MONTHS)	10.0	9.0	8.8	8.6	6.6
o AMTTR	2.5	2.3	2.2	2.1	1.4
o TMTTR	2.7	2.4	2.3	2.3	1.5
o UNASS RATIO	.1	.1	.1	.1	.1
o %CALLS W/UNSSGND	16.0	14.1	14.1	14.6	
NON-CORRECTIVE					
o MDAHPMR	.7	.8	1.0	.8	0.0
o MDAHRPR	2.6	2.3	2.3	2.1	
o MTTIAO	3.2	3.2	3.9	4.9	2.7
LOGISTICS					
o DOAPRC	.2	.3	.9	.9	
o MEPR	579.0	449.7	608.7	556.6	229.4
o FRUCR	1.3	1.5	1.6	1.2	
(SAMPLE SIZE)	2331	3484	3888	3649	

OPTION PROFITABILITY REPORT

	Q1 PROFITABILITY DOLLARS	Q1 PROFITABILITY %	Q2 PROFITABILITY DOLLARS	Q2 PROFITABILITY %
SAMPLE OPTION REVENUE	$1308333	100.0%	$1195441	100.0%
- DIRECT LABOR EXPENSE	$83521	6.3%	$83956	7.0%
- MATERIAL EXPENSE	$472363	36.1%	$375152	31.3%
- INVENTORY EXPENSE	$0	.0%	$0	.0%
GROSS MARGIN	$752449	57.5%	$736333	61.5%
- ALLOCATED EXPENSE	$255425	19.5%	$200776	16.7%
NET SAMPLE OPTION MARGIN	$497024	37.9%	$535557	44.7%

FOR INTERNAL USE ONLY

OPTION: 11750

OPTION PERFORMANCE REPORT

METRIC	FY 85 / FY 86 Q3	Q4	Q1	Q2	GOAL
CORRECTIVE ACTIVITY					
o ATBR (MONTHS)	3.7	4.0	3.7	4.1	
o AMTTR	1.8	2.1	1.8	1.7	
o TMTTR	2.0	2.3	2.0	1.9	
o UNASS RATIO	.2	.2	.2	.1	
o %CALLS W/UNSSGND	15.8	15.8	12.7	11.5	
NON-CORRECTIVE					
o MDAHPMR	1.9	1.8	1.8	1.8	
o MDAHRPR	2.2	2.2	2.1	2.0	
o MTTIAO	3.2	4.5	3.3	3.0	
LOGISTICS					
o DOAPRC	.2	.6	1.0	1.5	
o MEPR	306.1	345.6	268.6	266.4	
o FRUCR	1.1	1.5	1.3	1.2	
(SAMPLE SIZE)	1200	1599	1559	1576	

OPTION PROFITABILITY REPORT

	--Q1 PROFITABILITY-- DOLLARS	%	--Q2 PROFITABILITY-- DOLLARS	%
SAMPLE OPTION REVENUE	$2856165	100.0%	$2935287	100.0%
- DIRECT LABOR EXPENSE	$141293	4.9%	$126701	4.3%
- MATERIAL EXPENSE	$160378	5.6%	$137727	4.6%
- INVENTORY EXPENSE	$0	.0%	$0	.0%
GROSS MARGIN	$2554494	89.4%	$2670859	90.9%
- ALLOCATED EXPENSE	$425952	14.9%	$284922	9.7%
NET SAMPLE OPTION MARGIN	$2128542	74.5%	$2385937	81.2%

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OPTION: 11780

OPTION PERFORMANCE REPORT

METRIC	FY 85 / FY 86 Q3	Q4	Q1	Q2	GOAL
CORRECTIVE ACTIVITY					
o ATBR (MONTHS)	1.7	1.8	1.7	1.8	
o AMTTR	2.0	2.0	2.1	1.8	
o TMTTR	2.4	2.2	2.3	2.1	
o UNASS RATIO	.2	.2	.2	.2	
o %CALLS W/UNSSGND	18.3	16.4	15.2	16.3	
NON-CORRECTIVE					
o MDAHPMR	2.1	1.9	1.9	2.0	
o MDAHRPR	2.5	2.4	2.4	2.3	
o MTTIAO	3.1	4.3	5.5	4.6	
LOGISTICS					
o DOAPRC	.7	.9	.6	.5	
o MEPR	192.8	204.7	217.8	243.0	
o FRUCR	1.3	1.8	1.9	1.7	
(SAMPLE SIZE)	1102	1206	1112	833	

OPTION PROFITABILITY REPORT

	--Q1 PROFITABILITY-- DOLLARS	%	--Q2 PROFITABILITY-- DOLLARS	%
SAMPLE OPTION REVENUE	$4569466	100.0%	$3055438	100.0%
- DIRECT LABOR EXPENSE	$211960	4.6%	$148934	4.8%
- MATERIAL EXPENSE	$199462	4.3%	$149203	4.8%
- INVENTORY EXPENSE	$0	.0%	$0	.0%
GROSS MARGIN	$4158044	90.9%	$2757301	90.2%
- ALLOCATED EXPENSE	$708644	15.5%	$366385	11.9%
NET SAMPLE OPTION MARGIN	$3449400	75.4%	$2390916	78.2%

F O R I N T E R N A L U S E O N L Y

OPTION: PC350

OPTION PERFORMANCE REPORT

METRIC	FY 85 / FY 86 Q3	Q4	Q1	Q2	GOAL
CORRECTIVE ACTIVITY					
o ATBR (MONTHS)	12.8	11.1	9.7	10.4	
o AMTTR	.9	.9	.9	1.0	
o TMTTR	.9	.9	.9	1.1	
o UNASS RATIO	.0	.1	.2	.1	
o %CALLS W/UNSSGND	9.0	11.6	9.5	5.5	
NON-CORRECTIVE					
o MDAHPMR	.0	.0	10.6	.0	
o MDAHRPR	1.2	1.2	1.5	1.3	
o MTTIAO	3.0	.0	1.0	.0	
LOGISTICS					
o DOAPRC	.0	1.0	.4	.5	
o MEPR	208.8	232.9	177.9	177.4	
o FRUCR	2.0	1.8	1.4	1.5	
(SAMPLE SIZE)	714	1092	1060	1100	

OPTION PROFITABILITY REPORT

	--Q1 PROFITABILITY-- DOLLARS	%	--Q2 PROFITABILITY-- DOLLARS	%
SAMPLE OPTION REVENUE	$114202	100.0%	$129963	100.0%
- DIRECT LABOR EXPENSE	$9824	8.6%	$10719	8.2%
- MATERIAL EXPENSE	$39504	34.5%	$33713	25.9%
- INVENTORY EXPENSE	$0	.0%	$0	.0%
GROSS MARGIN	$64874	56.8%	$85531	65.8%
- ALLOCATED EXPENSE	$33871	29.6%	$27211	20.9%
NET SAMPLE OPTION MARGIN	$31003	27.1%	$58320	44.8%

F O R I N T E R N A L U S E O N L Y

OPTION: 1123

OPTION PERFORMANCE REPORT

METRIC	FY 85 / FY 86 Q3	Q4	Q1	Q2	GOAL
CORRECTIVE ACTIVITY					
o ATBR (MONTHS)	9.2	5.7	7.4	7.4	
o AMTTR	1.6	1.7	1.8	1.8	
o TMTTR	1.7	1.8	1.8	1.9	
o UNASS RATIO	.1	.2	.1	.1	
o %CALLS W/UNSSGND	11.8	13.7	10.1	11.0	
NON-CORRECTIVE					
o MDAHPMR	1.4	1.4	1.4	1.3	
o MDAHRPR	1.8	1.9	1.8	1.7	
o MTTIAO	1.5	1.9	4.7	3.5	
LOGISTICS					
o DOAPRC	.9	1.7	2.0	3.5	
o MEPR	114.1	66.3	90.6	71.2	
o FRUCR	.8	.9	1.1	.8	
(SAMPLE SIZE)	2379	2474	2191	1254	

OPTION PROFITABILITY REPORT

	--Q1 PROFITABILITY-- DOLLARS	%	--Q2 PROFITABILITY-- DOLLARS	%
SAMPLE OPTION REVENUE	$209195	100.0%	$120614	100.0%
- DIRECT LABOR EXPENSE	$103946	49.6%	$62464	51.7%
- MATERIAL EXPENSE	$33241	15.8%	$13876	11.5%
- INVENTORY EXPENSE	$0	.0%	$0	.0%
GROSS MARGIN	$72008	34.4%	$44274	36.7%
- ALLOCATED EXPENSE	$338206	161.6%	$167474	138.8%
NET SAMPLE OPTION MARGIN	($266198-)	(127.2%)	($123200-)	(102.1%)

OPTION: 1144

OPTION PERFORMANCE REPORT

METRIC	FY 85 / FY 86 Q3	Q4	Q1	Q2	GOAL
CORRECTIVE ACTIVITY					
o ATBR (MONTHS)	5.4	4.9	5.0	6.8	
o AMTTR	2.3	1.8	1.8	1.8	
o TMTTR	2.4	1.9	2.0	2.1	
o UNASS RATIO	.2	.2	.2	.2	
o %CALLS W/UNSSGND	16.0	19.7	16.2	16.0	
NON-CORRECTIVE					
o MDAHPMR	1.7	1.8	1.7	1.7	
o MDAHRPR	2.8	2.3	2.2	2.1	
o MTTIAO	3.8	2.5	3.3	12.8	
LOGISTICS					
o DOAPRC	1.0	.9	1.4	2.7	
o MEPR	214.7	175.9	222.4	196.3	
o FRUCR	1.1	1.1	1.3	1.1	
(SAMPLE SIZE)	1247	1434	1265	948	

OPTION PROFITABILITY REPORT

	Q1 PROFITABILITY DOLLARS	Q1 PROFITABILITY %	Q2 PROFITABILITY DOLLARS	Q2 PROFITABILITY %
SAMPLE OPTION REVENUE	$549628	100.0%	$422626	100.0%
- DIRECT LABOR EXPENSE	$110527	20.1%	$58877	13.9%
- MATERIAL EXPENSE	$58266	10.6%	$30430	7.2%
- INVENTORY EXPENSE	$0	.0%	$0	.0%
GROSS MARGIN	$380835	69.2%	$333319	78.8%
- ALLOCATED EXPENSE	$355337	64.6%	$146213	34.5%
NET SAMPLE OPTION MARGIN	$25498	4.6%	$187106	44.2%

F O R I N T E R N A L U S E O N L Y

OPTION: FUJ51

OPTION PERFORMANCE REPORT

METRIC	FY 85 / FY 86 Q3	Q4	Q1	Q2	GOAL
CORRECTIVE ACTIVITY					
o ATBR (MONTHS)	.0	63.0	395.0	477.8	
o AMTTR	.0	1.6	1.8	3.3	
o TMTTR	.0	1.7	1.8	4.5	
o UNASS RATIO	.0	.1	.6	.2	
o %CALLS W/UNSSGND	.0	14.3	42.9	20.0	
NON-CORRECTIVE					
o MDAHPMR	.0	.0	.0	.0	
o MDAHRPR	.0	1.7	4.5	5.3	
o MTTIAO	.0	.0	.0	.0	
LOGISTICS					
o DOAPRC	.0	.0	.0	.0	
o MEPR	.0	.0	.0	.0	
o FRUCR	.0	.0	.0	.0	
(SAMPLE SIZE)	0	189	790	637	

OPTION PROFITABILITY REPORT

	--Q1 PROFITABILITY-- DOLLARS	%	--Q2 PROFITABILITY-- DOLLARS	%
SAMPLE OPTION REVENUE	$60717	100.0%	$66471	100.0%
- DIRECT LABOR EXPENSE	$946	1.5%	$501	.7%
- MATERIAL EXPENSE	$0	.0%	$0	.0%
- INVENTORY EXPENSE	$0	.0%	$0	.0%
GROSS MARGIN	$59771	98.4%	$65970	99.2%
- ALLOCATED EXPENSE	$3634	5.9%	$1502	2.2%
NET SAMPLE OPTION MARGIN	$56137	92.4%	$64468	96.9%

F O R I N T E R N A L U S E O N L Y

1986 VAX

Positioning Study

Prepared for

High Performance Systems and Clusters

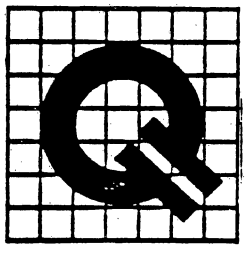
Mid-Range Systems Business

Product Marketing Group

FORUM '86

by

DS/Customer Information Group



SEPTEMBER 1986

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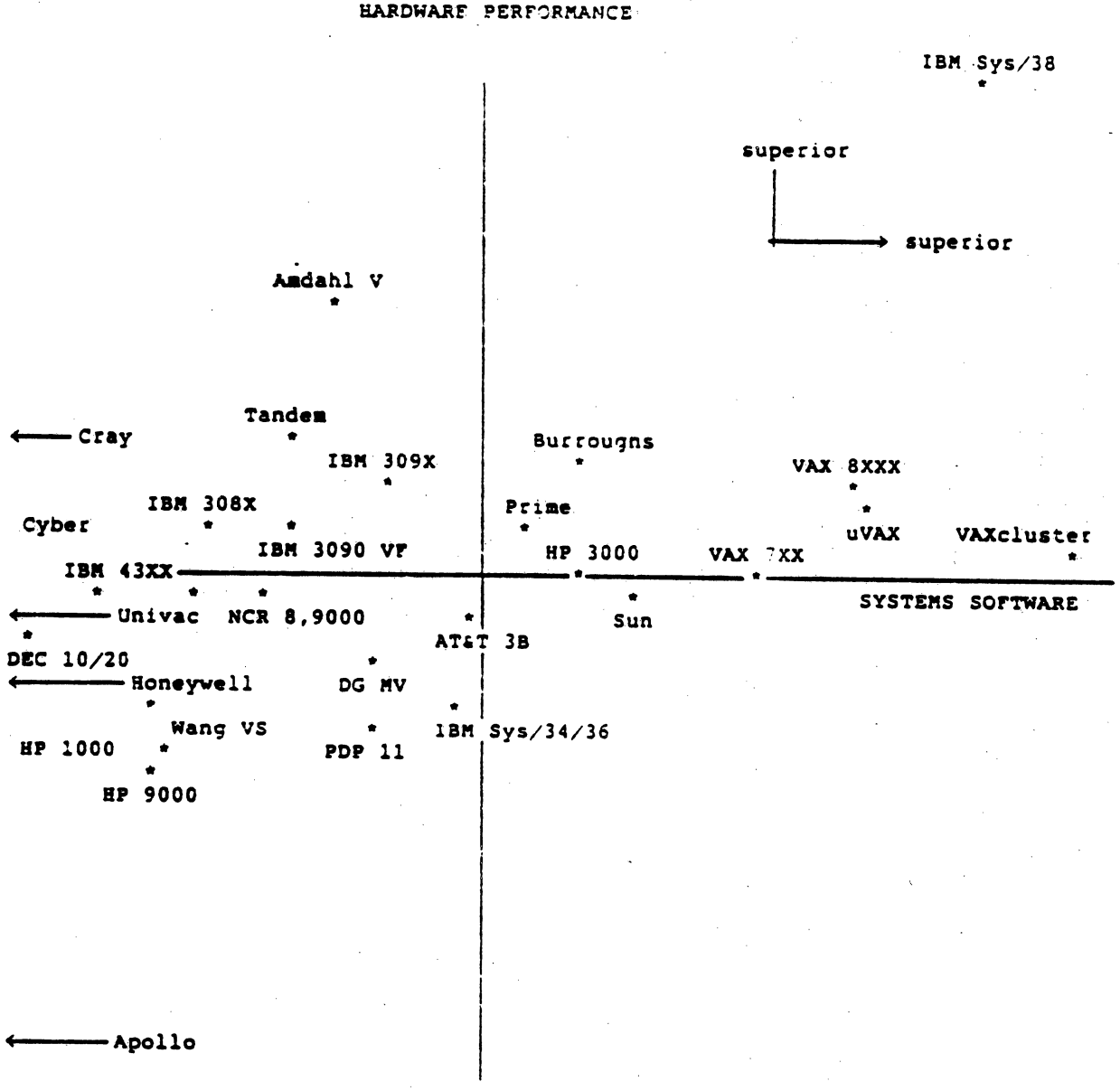
1986 VAX

Positioning Study



SEPTEMBER 1986

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1986 VAX POSITIONING STUDY

MANAGEMENT SUMMARY

This third implementation of the VAX Positioning Study reveals a dramatic improvement in the market situation for Digital relative to earlier versions of the study. The researchers believe that Digital has an unprecedented opportunity to gain market share from its only strategic competitor, IBM, provided that the company continues to make progress in areas important to commercial customers. In technical markets it appears that no other competitor represents a serious threat to take share from Digital at this time.

While the current market situation is quite favorable for Digital, previous VAX studies indicated a somewhat different situation. The reader should carefully consider the findings from the previous studies to gain a more balanced perspective on the FY86 VAX Positioning Study results.

FINDINGS FROM THE FY84 AND FY85 VAX STUDIES

The FY84 study established that Digital's leadership of the technical and scientific markets was primarily due to the richness of the VMS software environment and the availability of technical applications software. Customers perceived VMS as the world's best operating system, and Digital's high level languages as second to none. The FY84 study further established that customers perceived Digital as an arrogant company with which it was difficult to do business, and that Digital's systems were not market leaders in reliability. These shortcomings, along with Digital's lack of strength in transaction processing and data base management, precluded Digital from seriously challenging IBM in commercial markets.

The FY85 study was implemented in the U.S. and six other countries, just prior to volume shipment of the VAX 8600. This study was the first in which it was concluded that IBM was Digital's only strategic competitor (this was evident but not conclusive in the FY84 study - it became conclusive when the worldwide results of the FY85 study were considered). The FY85 study conclusions, therefore, focused on Digital to IBM comparisons. It was shown that Digital customers buy computers by evaluating technical features, while IBM customers consider a balance among commercial features, customer interaction (sales and marketing), and hardware reliability. The study further revealed striking differences in the purchase criteria among the seven countries, particularly regarding customer expectations for system reliability.

But the overriding finding from the FY85 VAX study was that Digital's market position was beginning to weaken. VAX system ratings dropped from 8th to 15th in Compute Power, 1st to 6th in Operating Systems, 16th to 18th in Ease of Doing Business, and so on. While customers still preferred VAX's for scientific applications, they were finding it harder to justify their feelings. The researchers believe that if the 8600 had not shipped when it did, within six to twelve months Digital would have entered into a period of decreasing market share.

FY86 VAX STUDY FINDINGS

Three major VAX Positioning Study findings are highlighted in this management summary. First, customers appear to be gaining in sophistication and taking more responsibility for their computing strategies. Second, most metrics on VAX systems are very positive. Third, the metrics on IBM's mainframe products have deteriorated since the last implementation of this study.

While the current market scenario for Digital is very positive, the company must be extremely careful not to be overconfident. Only two years ago it was the Digital metrics that were declining. With the resources available to IBM, they can regain momentum very quickly.

1) CUSTOMERS ARE CHANGING

One of the more intriguing findings of the FY86 VAX Positioning Study is that customer priorities pertaining to their computer purchase decision may be changing. These changes manifest through the way in which customers assigned importance to an array of computer system attributes. Customers are assigning a higher priority to the base computing technologies, while de-emphasizing vendor characteristics. Consider this table:

INCREASING IMPORTANCE	DECREASING IMPORTANCE
Compute Power	Vendor Integrity
TP Responsiveness	Software Support People
Family Compatibility	Require Minimal On-Site Expertise
Real-Time Interface	Ease of Doing Business with Vendor
Price of Software	Business/Commercial Software
Memory Management	

With a couple of exceptions, the above table is indicative of customers focusing more on base technologies, and less on vendor attributes. In particular, vendor integrity, vendor software support, vendor business practices, and the need for minimum on-site expertise have all decreased in importance.

One conclusion from this data set is that these customers may be taking more responsibility for the application of computers to their business problems. Fewer customers appear to be buying applications based on a vendor's recommendation, and using vendor software support people to work with vendor-supplied applications software. Instead, customers appear to be building in-house expertise. This study suggests that customers may be discriminating among vendors more and more at the base computing technology level, by evaluating compute power, and real-time responsiveness, for example. They appear to be looking for vendors that can ensure their futures by building compatible families of systems.

This trend is most prevalent among IBM mainframe customers. As will be shown later in this management summary, IBM 4300-3080-3090 customers are exhibiting unprecedented levels of dissatisfaction. It is possible that these customers are no longer willing to take IBM's word on when and how to buy systems (thereby decreasing the importance of vendor integrity). Rather, these customers may be evaluating the amount of MIPS that are truly sufficient for their applications, and the level of TP responsiveness they really need. They are also looking more closely at the price of software. A final point is that the decrease in importance of networking may be due to the frustration of IBM mainframe customers regarding their lack of a competitive set of networking products (evidence shown later in this section).

This is a most favorable development for Digital. Digital has always led with its product set, and has been most successful in environments in which customers were willing and able to take responsibility. It appears that many more customers have recognized the strategic importance of computing to their businesses, and have understood the need to take more responsibility for their computing strategies.

Based on the importance of these findings to Digital, it is suggested that further research be conducted to develop more evidence, and to test more explicit hypotheses associated with customer buying behavior for applications.

2) THE FAVORABLE CUSTOMER VIEW OF VAX SYSTEMS

This is the first implementation of the VAX Positioning Study since the complete new family of VAX systems have been shipped. Customer perceptions of these new VAX products are very favorable. Consider the perceptual ratings of the major VAX systems, relative to a total of 29 competitive computer systems, on these attributes:

ATTRIBUTE	VAX 8000	VAX 11/700	MICROVAX	VAXCLUSTERS
Operating Systems	9	7	5	3
Software Tools/Utilities	5	8	4	3
Ease of Use	7	11	8	3
Family Compatibility	6	5	2	3
High Level Languages	3	4	5	1
Documentation	3	4	7	2
Architecture	6	9	7	3
Word Processing	6	8	5	9
System Price	7	17	9	8
Graphics	8	9	5	6
Scientific/Engineering S/W	7	6	8	5
Networking	3	6	4	2
Overall Quality	5	9	3	1

No other vendor provides systems that are as consistently in the top ten on such a wide array of attributes as Digital with its VAX systems. Keep in mind, however, that these scores represent significant improvement over Digital's position in the FY85 VAX Positioning study.

In summary, customers widely recognize Digital's VAX systems as the industry leaders in system software, technical applications software, networking, family compatibility, architecture, and overall quality (where overall quality means customer satisfaction).

3) THE DETERIORATION OF IBM MAINFRAME LEADING INDICATORS

The positive market view of VAX systems is in clear contrast to the negative customer ratings of IBM mainframe products. There has been a major drop in the ratings of IBM mainframe products on many attributes. Consider these customer ratings of IBM mainframes on the same table of key attributes as shown above for VAX systems:

ATTRIBUTE	4300	3080	3090
Operating Systems	23	22	8
Software Tools/Utilities	22	14	6
Ease of Use	27	28	22
Family Compatibility	16	13	9
High Level Languages	18	17	7
Documentation	15	13	19
Architecture	20	13	12
Word Processing	21	22	16
System Price	24	27	29
Graphics	21	15	12
Scientific/Engineering S/W	22	18	17
Networking	15	11	8
Overall Quality	18	10	8

In contrast to Digital's VAX system, IBM's mainframe products are rarely in the top ten on these key attributes, and the 4300 is frequently not in the top 20 (which is an extremely negative finding considering there are only 29 systems being rated).

While these attributes, which are only 13 of the 37, are the areas in which VAX systems exhibit the most strength, the magnitude of the IBM mainframe deficiencies cannot be overstated. Their software environment, architecture, ease of use, and even word processing are badly lagging according to the market. Clearly, their family compatibility problem is understood by customers. It appears that IBM would have to take dramatic action to turn around these perceptions, and that some, such as their software environment, are deeply inherent in their architecture (which is seen as lagging), and not readily improved.

One important exception to the above finding in IBM's product line is the System /38. This product, which is optimized for small and mid-range transaction processing applications, is most favorably regarded by its customers. The System /38 was rated first or second on most of the system software attributes (again, the system is not general purpose, but optimized for one environment), among the top five on all of the hardware attributes, and in the top three on the reliability attributes. The System /38 is the most favorably rated product in IBM's product line by a good margin. The only major deficiencies of this system are its scientific/engineering features, and its compatibility with other IBM products.

In summary, Digital appears to have an unprecedented market opportunity to take share from IBM by focusing marketing efforts on dissatisfied IBM mainframe customers. Many IBM mainframe customers appear to be interested in seeking alternatives to their current computer vendor.

4) VAX SYSTEM DEFICIENCIES

While VAX systems have improved, and IBM mainframes have dropped in customer ratings, there are still many attributes on which IBM systems lead VAX. These are:

* Transaction Processing Responsiveness
* Mass Storage
* System Never Fails
* Hardware Reliability
* Software Support
* Business/Commercial Software
* Terminals/Workstations/PC's
* Salespeople

These eight attributes are the key determinants of preference and purchase in commercial applications. These are therefore areas in which VAX systems must improve if Digital is to take advantage of the opportunities due to current customer dissatisfaction with IBM mainframes.

Even in these areas of VAX system shortcomings, the trend appears positive. In hardware reliability, VAXclusters were rated 5th, and MicroVAX was 11th. Customer perceptions of VAX systems on file and database management are now almost on par with IBM's systems, and this attribute is no longer on the VAX shortcoming list. Digital has improved slightly on ease of doing business with vendor, while IBM has fallen to 19th place for the 3080 and 14th place for the 3090. This attribute is no longer a strategic advantage for IBM, although customers perceived difficulties in transacting business with both companies.

5) PREFERENCE

Measures of customer preference for computer systems were taken in both business/commercial applications and scientific/engineering applications. Preference is the best predictor of short to medium term sales.

In business and commercial applications, preference for IBM systems has not yet shown the same down trend as the perceptual measures. These customers, who tend to be slower to react to new technology than technical customers, have not yet developed strong preference for the new VAX systems. Consider this table:

BUSINESS/COMMERCIAL COMPUTER PREFERENCE

Rank	System
1	IBM System /38
2	IBM System 34/36
3	IBM 4300
4	HP 3000
5	VAX 11/700
6	VAX 8000
7	IBM 3080
8	IBM 3090
9	MicroVAX
10	VAXclusters

IBM still leads in preference. There seems to be a strong positive trend for the System /38. and a stable position for the 4300. The preference for IBM's large mainframes does appear to be decreasing.

While Digital is in the top ten four times. its overall preference share appears to have increased only slightly since previous studies. The VAX 11/700 dropped from tied for 2nd to 5th. This decrease is offset by the addition of MicroVAX. VAX 8000. and VAXclusters in the top ten. Note that the 8000's. MicroVAX and VAXclusters still trail the 11/700 family in preference ranking. This may be due to the slower process for developing preferences in the commercial markets.

In summary. although perceptions of IBM systems have begun to deteriorate. preference for them in business and commercial applications remains strong. although the 3080/3090 series is showing some signs of weakness. VAX systems must overcome shortcomings on some commercial attributes if they are to more seriously challenge IBM for commercial market leadership. The trend is positive for VAX on these metrics.

In technical markets. VAX systems are by far the most preferred systems. with no serious challengers evident at this time. These are the ten most preferred systems for scientific applications:

SCIENTIFIC/ENGINEERING COMPUTER PREFERENCE

Rank	System
1	VAX 8000
2	VAX 11/700
3	MicroVAX
4	VAXclusters
5	CDC Cyber
6	HP X000
7	APOLLO DOMAIN
8	AMDAHL V
9	PRIME 50
10	IBM 3090

The gap between the VAX systems and the others is large.

As is evident from the table. VAX systems are in a strong leadership position in technical markets. No other general purpose systems are seen as an alternative to VAX for scientific customers. Only one IBM system is in the top ten.

SUMMARY AND CONCLUSIONS

This study reveals that VAX systems are currently the unchallenged market leader for engineering/scientific applications, and have potential to gain on IBM in business/commercial applications. To maintain VAX leadership in technical markets, while exploiting the opportunities in commercial markets, these concepts should be considered:

* There is evidence in this study that customers are taking more responsibility for their computing strategies. This is a favorable trend for Digital, which wins sales with products. Digital should proactively work to encourage this trend among customers, and ensure that company strategies do not prevent customers from becoming more responsible. Two key areas that might prevent customers from taking responsibility are closed architectures and packaging things that customers do not want. These strategies may not be in Digital's interest in the long run. Further, we should encourage joint planning and shared responsibility with customers whenever possible (such as at Forum'86).

* Digital's leadership in technical markets is due to VAX superiority in system software, architecture, technical applications software, and other base technologies. Since these markets are driven by technical factors, they are prone to rapid change. The challenges to Digital on the desk, in parallel processing, and by network-based competition could become strategic threats in a very short time frame. Digital must not be complacent about its current market strength, and continue to ensure that its products are leadership in technology.

* Digital should realize increasing opportunities to exploit IBM deficiencies in the commercial mainframe market in the near term. However, there are an array of attributes deemed important by commercial customers on which VAX is perceived as lagging (TP, storage, reliability, etc.). Digital must be careful in selecting commercial opportunities, and aggressively work to overcome these shortcomings. If we are successful, Digital should be in a position to gain significant market share.

We clearly must be careful not to be overconfident based on Digital's current market position. However, we should also take great pride in the strides that the company has made in the past two years. We have introduced products that have been very well received by customers, and now have opportunities for future growth that are unprecedented in Digital history.

INTRODUCTION TO THE 1986 VAX POSITIONING STUDY

The 1986 VAX Positioning Study is the third in a continuing series of annual research projects conducted by the DS Customer Information Group. The major objective of these projects is to provide Digital Management with an overall assessment of the company's competitive position in the mid-range and large computer systems market. Customer perceptions about the strengths and weaknesses of Digital products - as well as those of the competition - are examined in the study. Analysis of customer needs and of their perceptions about leading system vendors will help identify those elements of product and business strategy that are needed in order for the company to be successful in selected market segments.

This report documents the results of the 1986 study. The researchers believe it to be critical for Digital's Engineering Management to consider these results. If further information or analyses are required. please contact the DS Customer Information Group.

BUSINESS PROBLEM: CUSTOMER INFORMATION

During the past two years Digital has introduced products that have had a significant impact on its three major product areas — low-end. mid-range and high performance systems. This has led to Digital being the only computer vendor to offer a line of computing products. from the desktop to the mainframe. having compatible architecture and allowing information sharing.

As a result of newly introduced product line enhancements. Digital is now perceived as positioned to meet the information processing needs of a much wider variety of application segments than those of its traditional customer base.

However. the euphoria with which Digital has been showered of late may serve to hide deficiencies. both in the company's product set and in its ability to implement new strategies. It is especially necessary during good times to be circumspect. and the need for objective and clear research into customers' requirements has never been greater. And although the overall position appears positive. it is clear that any perceived deficiencies in Digital's product set. as well as in its delivery strategies need to be investigated.

To avoid problems reminiscent of those the US auto industry encountered in the seventies when most major manufacturers lost substantial market share to foreign competition due to neglecting changes in exogenous variables (e.g. increasing oil prices) and consumer needs. in-depth and ongoing research continues to be required to focus in detail on the needs and characteristics of major application segments. An especially strong need exists for continued research into inter-segment differences.

METHODOLOGY: A MODEL

A well-known marketing model, on which this study is based, explaining the relationship between customer information and the purchase decision-making process is shown in Fig 1.

The model begins with defining who the customer is. Different types of customers have different generic needs and levels of experience with computers. The awareness component of the model is based on the premise that different customers will tend to have different levels of awareness of the products. Their personal experience with products tends to yield certain perceptions of the products on various attributes. At the same time, the importance, or utility, of the attributes to customers differs.

The objective utilities are based on customer requirements for specific levels of tangible attributes (e.g. MIPS per computer system). The subjective utilities are a measure of the objective utilities when considered in conjunction with less tangible attributes, such as image of the vendor, sales and support. The importance of the attributes, along with attribute perceptions, will lead to preference for alternative computer products. These preferences, along with exogenous variables such as the state of the economy, will lead to purchase. Subsequent to purchase, the customer will either be satisfied or dissatisfied with the product.

The study measures most of the above components of the customer information processing model with respect to the mid-range and large systems market. Given that these components are inter-dependent, changes in one component can be interpreted as leading indicators of changes in subsequent components. Thus, the study can be used to monitor changes over time, so that we may anticipate trends in our industry and the effects that these trends might have on Digital.

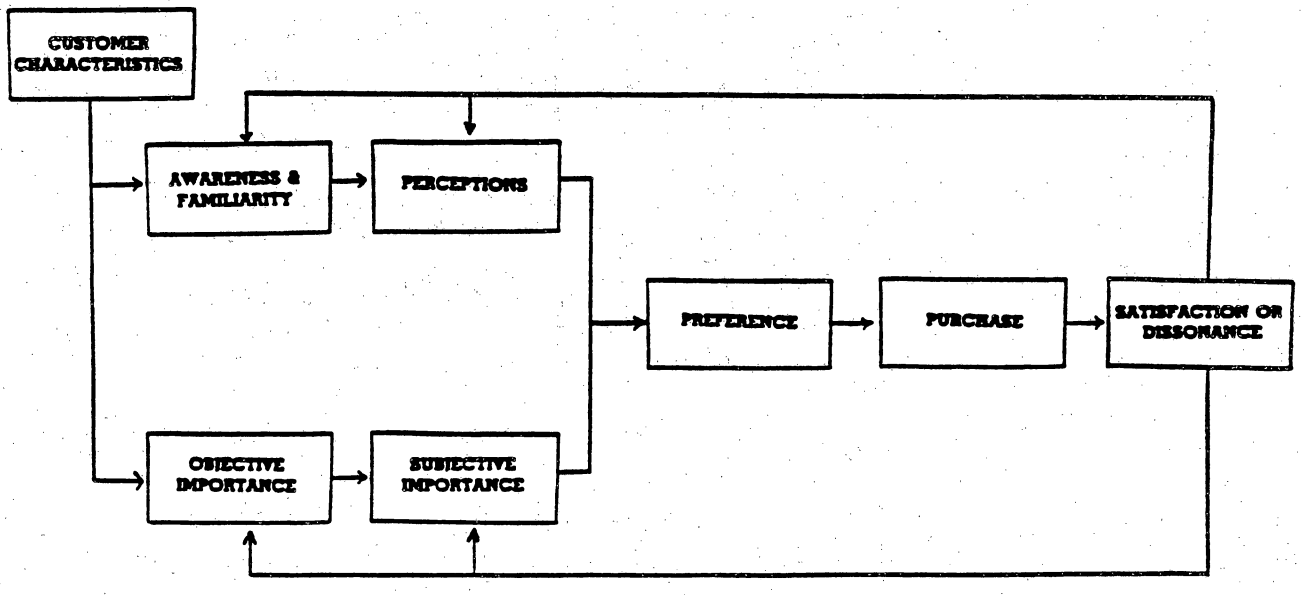


Fig. 1

OBJECTIVES

The 1986 VAX Positioning Study is a comprehensive market research project conducted by the Distributed Systems Customer Information Group with the support of the High Performance Systems Group, the Mid-Range Systems Business Group and the Product Marketing Group.

The Study has been designed to provide quantitative, defensible information on changing customer computing requirements, as well as competitive positioning (from the customers perspective) of leading computer systems. The list of the 27 major systems whose usage and preference is analyzed in the study appears in Figure 2. The list includes major mid-range and high-performance offerings from both IBM and Digital, leading systems from traditional minicomputer vendors such as Data General, Prime, HP and Wang, and UNIX-based products from start-ups such as Convex, Alliant and Pyramid. For competitive positioning purposes, an expanded list of 29 systems (the above systems together with PDP-11 and DEC 10/20) is used.

Issues currently having high strategic priority for Digital have also been covered in this year's study. These high priority issues include customers' computing styles, and mass storage and reliability requirements. Specifically, the goals of the study consist of addressing the following sets of questions about both the mid-range and high performance computer systems markets:

* Who are the customers of major computer systems? What are their characteristics (e.g. organizational annual revenue and budget level, structure of purchase decision-making unit, primary computing application)?
* What is the extent to which customers are aware of major computer systems? Which systems are they currently using and which have they used in the past?
* What are the criteria that customers use in their purchase of computer systems? How do systems from major vendors rate along these criteria? What criteria are used by customers in their system preference formation process, for major applications?
* What are customer requirements in the areas of computing configuration, mass storage and reliability?

SAMPLING SCHEME

The research instrument was a mailed questionnaire, which was sent to a stratified random sample of 40,000 potential respondents. For the purpose of the 1986 study, the mail-out was limited to the U.S. The sampling strategy of 50% computer installations (primarily commercial computer users), 30% technical and scientific, and 20% OEM's was implemented to assure an accurate representation of the entire computer professional population. Approximately 3500 questionnaires were returned, yielding a return rate of nearly 9%. Digital remained anonymous in the study.

SYSTEMS USED IN THE 1986 VAX POSTITIONING STUDY

Apollo Domain
IBM System /38
HP 3000

Tandem Nonstop
Digital VAX 11/7XX
AMDAHL V Series

Pyramid 9XX
IBM 43XX
Digital VAX 8XXX

Elxsi 6400
IBM 308X
DG MV

Univac 1100
IBM System /88
Prime 50 Series

Wang VS
IBM 309X
Cyber 700/800

Burroughs A/B
Alliant FX
IBM 3090-VF

Digital VAXclusters
Stratus /32
Convex C-1

NCR 8000/9000
Digital MicroVAX
IBM System 34/36

FIGURE 2

1.0 DEMOGRAPHICS

This chapter provides general background information as well as data on computer applications for the sample of respondents in the 1986 VAX Positioning Study. In particular, respondents were asked to indicate the functions and revenues of their organizations; their job functions; their involvement with and understanding of the computer purchase process in their organizations; the annual computer budgets for their organizations, their primary applications of computers; and the computer tools that they use in their applications.

The major findings, detailed in the sections below, are:

* The sampling strategy succeeded in providing good coverage of all major industry and application segments, as well as business sizes.
* Most respondents are heavily involved in the computer purchase process in their organizations. MIS/EDP management, general management, and to an increasing extent, end-users have considerable influence over the computer purchase decision.
* Generic productivity enhancement tools such as word processing and spreadsheets are extremely important to both commercial and technical customers.
* Relative to commercial customers, technical customers consider system management tools and networking tools/applications (such as file servers and electronic mail) to be more important.

1.1 RESPONDENT BACKGROUND

Figure 1.1 shows the results for the respondents' organizational function. Observe that both "low tech" and "high tech" industries are well represented in the sample. Additionally, research institutes, engineering houses, and the educational community have significant representation. [Note that 2% of the sample of 3,500 respondents represents 70 respondents, a sufficiently large number for performing detailed statistical inquiries.] The annual revenues (or, if non-profit, funding levels) for respondents' organizations in the most recent fiscal year are provided in Figure 1.2. Roughly half of the respondents belong to organizations with annual revenues of less than $20 million while just over 15 percent indicate yearly revenues of greater than $500 million. Hence, small, medium, and large business customers are each well represented in the sample.

Respondents' job functions are displayed in Figure 1.3. Nearly one-third of the sample classify themselves as MIS/EDP Managers, a result not unexpected because of the sampling scheme employed (i.e., 50% of the questionnaires were mailed to a "computer installed base" list, with contacts drawn largely from MIS/EDP departments). Second-most numerous is the Owner/Director category with nearly 18% of respondents, a result attributable to the large representation of small business in the sample. Lastly, Engineers, Software Developers, and various non-technical job functions are well represented.

ORGANIZATIONAL FUNCTION

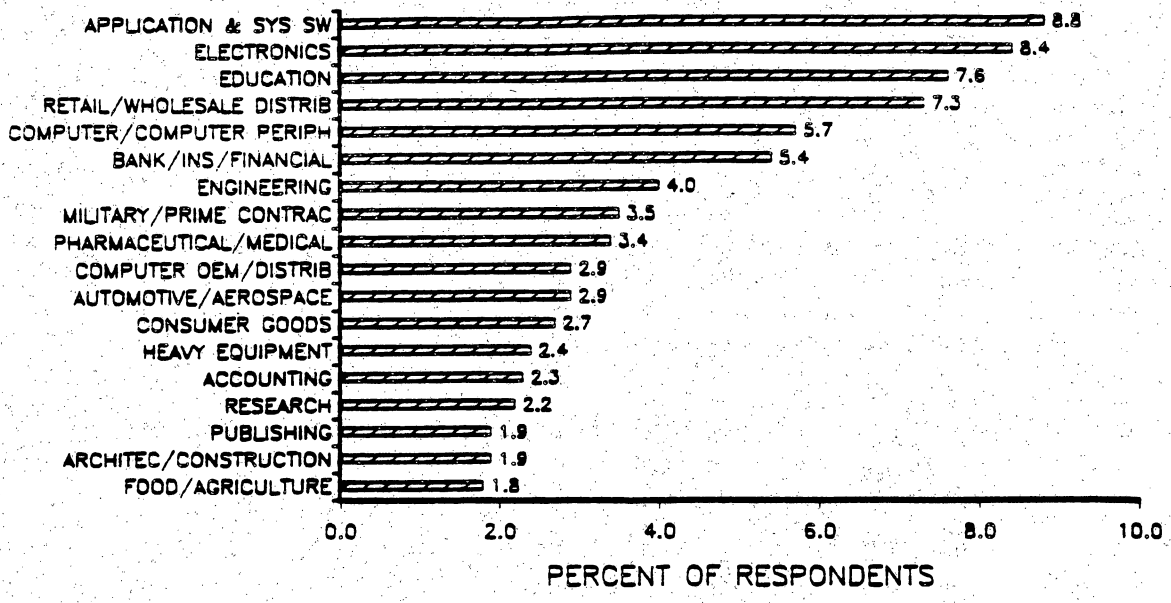


FIGURE 1.1

ORGANIZATION REVENUE/FUNDING LEVEL

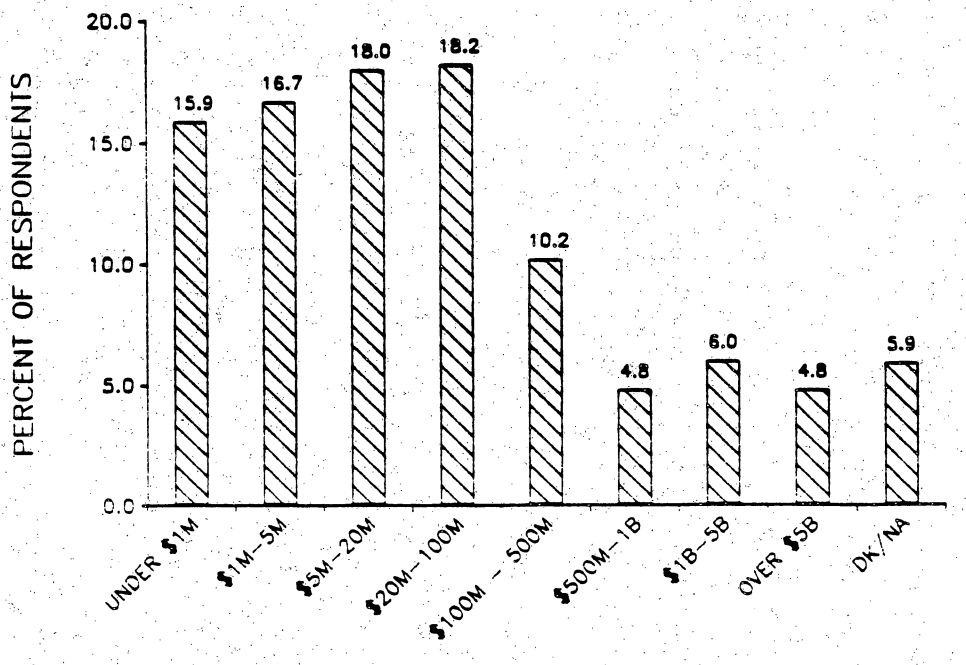


FIGURE 1.2

RESPONDENT FUNCTION

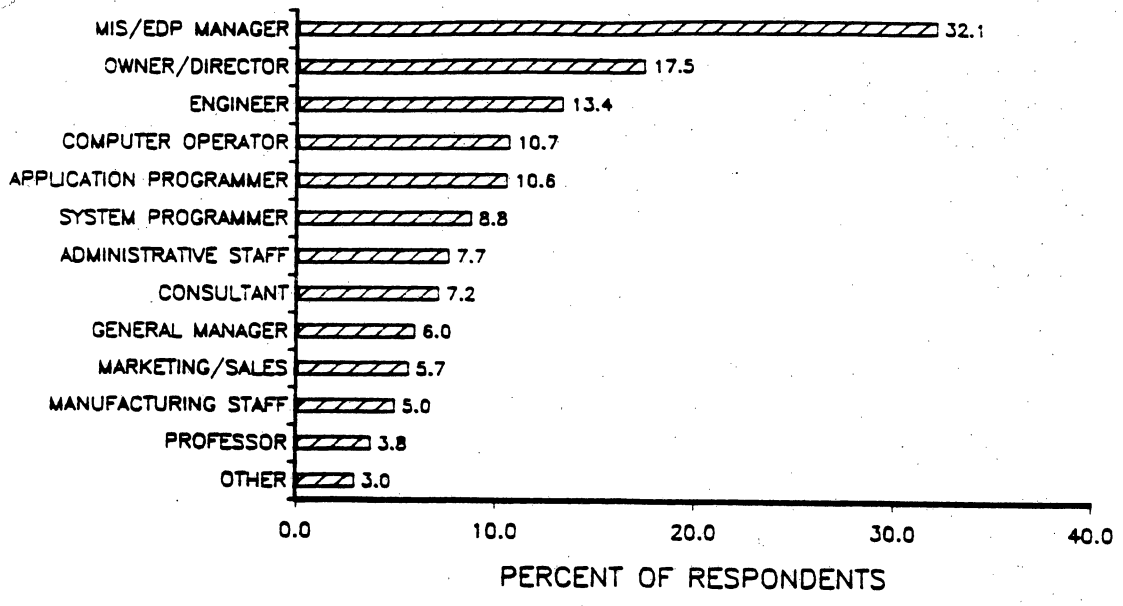


FIGURE 1.3

RESPONDENT PURCHASE INVOLVEMENT

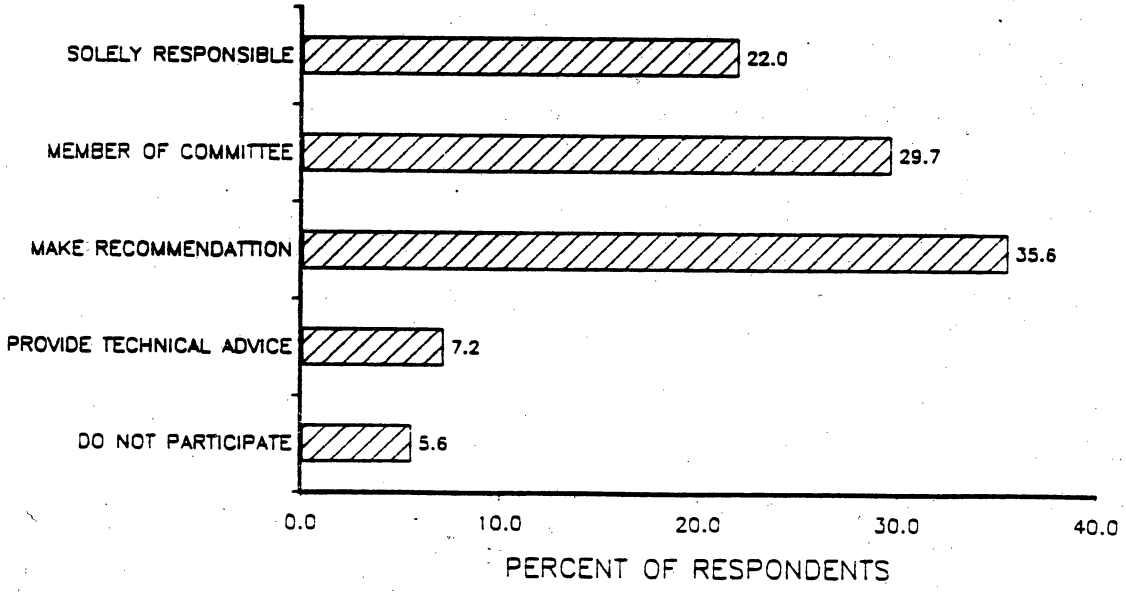


FIGURE 1.4

Results concerning the computer purchase process and computing budgets for respondents' organizations are presented in Figures 1.4 through 1.7. Clearly visible from Figure 1.4 is the fact that most respondents in the sample are heavily involved in their organizations' computer purchase process. Over half of the respondents state that they are either "solely responsible for the computer purchase decision" or a "member of a committee responsible for the computer purchase decision". Figure 1.5 shows that MIS/EDP management, General Management, and, to a surprisingly great extent, End-Users are most often cited by respondents as having a major influence over the computer purchase decision in their organizations.

Figure 1.6 provides information regarding the highest level for which a respondent is familiar with his or her organization's computer budget. Nearly half of the respondents are familiar with the budget for their entire company/organization while approximately one-third are familiar with the computing budget at the group and/or division levels. Finally, Figure 1.7 presents results for the annual computer budget for the highest level within the organization for which respondents are familiar with the budget. Nearly half of the respondents specified annual computing budgets of less than $100 thousand while only about 8% specified budgets of greater than $2 million. If one only considers respondents from organizations with revenues of greater than $500 million (representing about 15% of all respondents), the computer budgets are considerably higher, on average. In fact, about 43% of respondents from these larger organizations indicate computer budgets of greater than $2 million. These are the organizations that account for the vast majority of computer spending.

1.2 COMPUTER APPLICATIONS AND TOOLS

Figure 1.8 shows the primary applications of computers for the respondents in the sample. Nearly one-third of the respondents indicate MIS/Finance/Administration as their primary computing application. Based on the background data (in particular, job function) above, most of these are MIS professionals (as opposed to Finance/Admin. professionals). Other application areas with significant representation include Software Development, Office Applications, Research/Scientific, Design/Engineering Automation, Manufacturing/Inventory, and Order Processing/Marketing/Sales.

Throughout the remainder of this report, a certain level of focus is placed on two broad application segments. The first segment, "Business/Commercial", consists of respondents whose primary applications of computers are either MIS/Finance/Administration, Office Applications, Manufacturing/Inventory, or Order Processing/Marketing/Sales. The second segment, "Scientific/Engineering", consists of respondents whose primary computing applications are either Software Development, Research/Scientific, or Design/Engineering Automation.

FUNCTIONS HAVING MAJOR INFLUENCE OVER PURCHASE DECISION

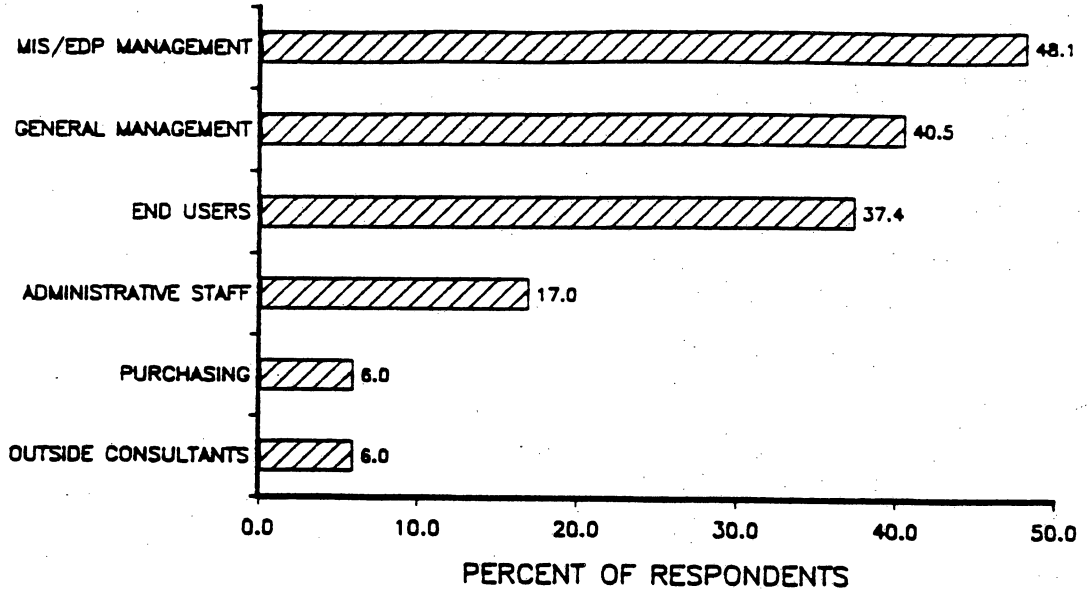


FIGURE 1.5

HIGHEST ORGANIZATIONAL LEVEL BUDGET FAMILIARITY

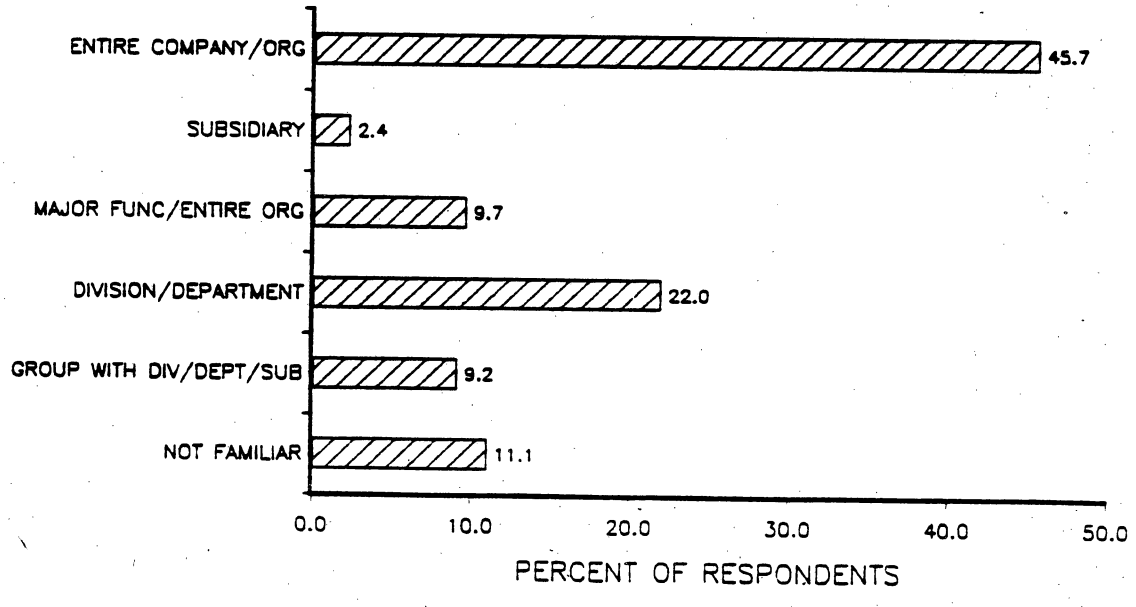


FIGURE 1.6

ANNUAL COMPUTING BUDGET

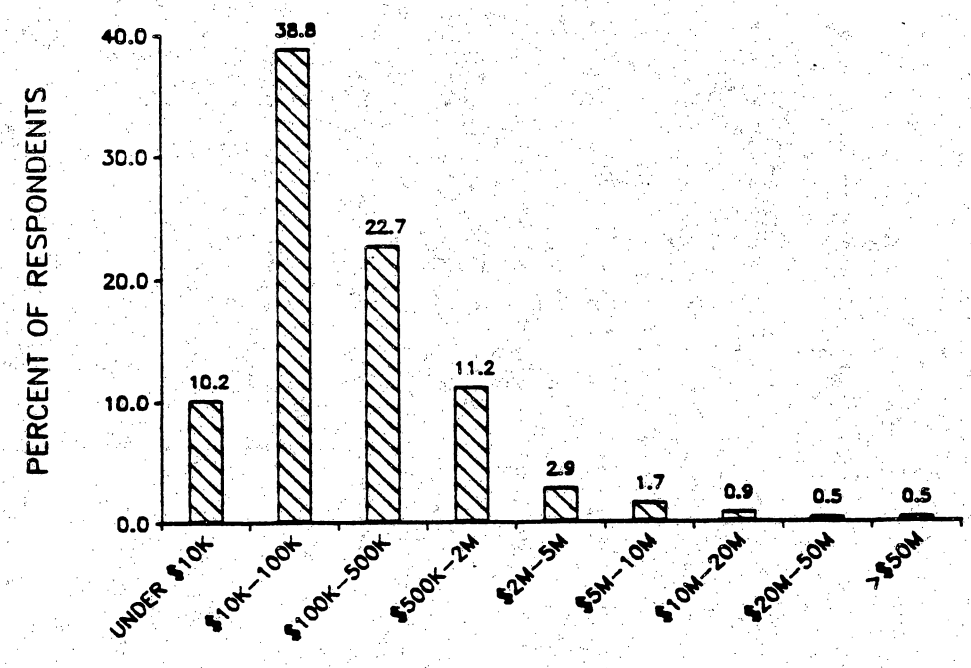


FIGURE 1.7

PRIMARY COMPUTING APPLICATION

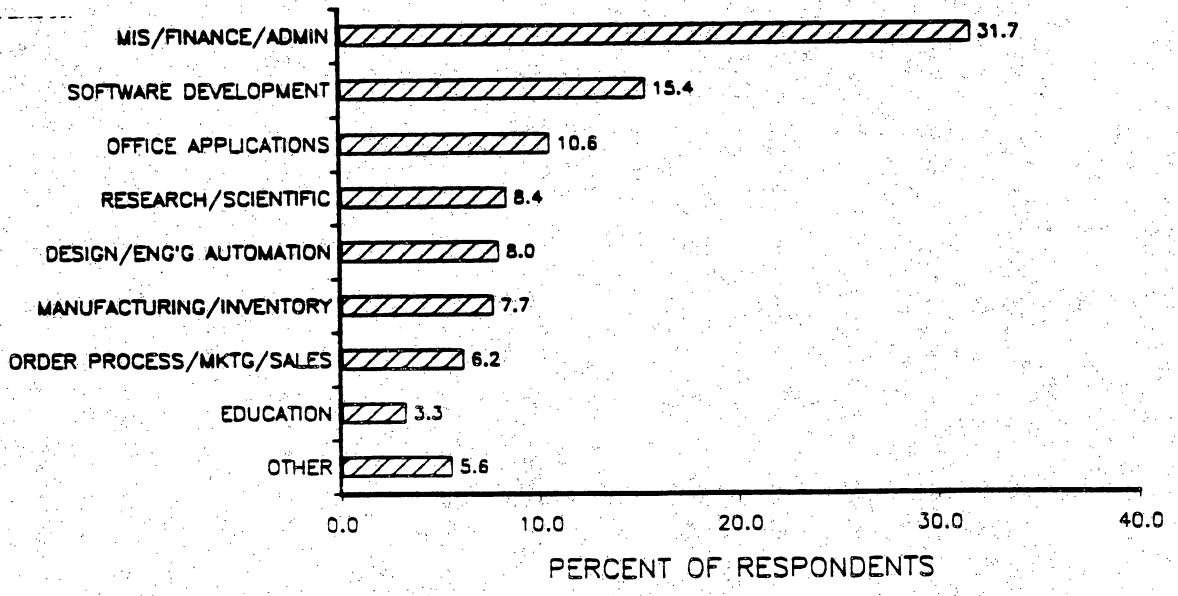


FIGURE 1.8

Respondents were also asked to rate the importance of a variety of computer tools to their job function. Figures 1.9 and 1.10 present rankings of the ten most important tools for respondents in the "Business/Commercial" and "Scientific/Engineering" application segments, respectively. Generic productivity enhancement tools such as Word Processing and Spreadsheet software as well as both Internally Developed Software and Purchased Application Software are extremely important to respondents in both application segments. Mathematical Simulation/Modeling, Electronic Mail, File Server, and System Management Tools have a higher degree of importance to respondents in the "Scientific/Engineering" segment while Inventory Management Software, Order Processing/Sales Records Software, Transaction Processing Software, and Financial Modeling Software are more important to the "Business/Commercial" segment. Lastly, Relational Data Base software and Data Dictionary are important tools for both segments.

SCIENTIFIC/ENGINEERING TOOL IMPORTANCE

1. Word Processing
2. Internal Application Software
3. Spreadsheet
4. Relational Data Base
5. Purchased Application Software
6. Mathematical Simulation/Modeling
7. Electronic Mail
8. File Server
9. System Management Tools
10. Data Dictionary

FIGURE 1.9

BUSINESS/COMMERCIAL TOOL IMPORTANCE

1. Word Processing
2. Spreadsheet
3. Inventory Management Software
4. Order Processing/Sales Records Software
5. Purchased Application Software
6. Internal Application Software
7. Transaction Processing Software
8. Relational Data Base
9. Data Dictionary
10. Financial Modeling Software

FIGURE 1.10

2.0 COMPUTER SYSTEM USAGE AND PREFERENCE

This chapter presents information on computer system usage and preference. Results are provided for the overall sample as well as for the "Business/Commercial" and "Scientific/Engineering" application segments. The chapter also shows joint (i.e., multiple system) usage and migration (i.e., vendor switching) data for Digital and IBM customers. Lastly, information on current and estimated future usage of UNIX and vendor proprietary operating systems is provided.

The major findings, discussed in depth in the sections below, are:

* With its new generation of VAX processors, Digital has extended its leadership in technical markets. Both usage of and preference for VAX has increased among technical professionals since the 1985 study. In contrast, preference for IBM systems (in particular, the 43XX) is down significantly.
* MicroVAX and VAX 8XXX are predominantly being sold to the existing VAX customer base. The great majority of VAX 8XXX and MicroVAX users are either current or former users of VAX 11/7XX.
* Most VAX 8XXX systems are being tied to existing VAX 11/7XX systems via VAXclusters and networking. In addition, IBM products are used jointly with Digital VAX products as often as they are used with other IBM products. These findings are a tribute to the VAX family's strengths in compatibility and connectivity.
* IBM's dominance of commercial markets is not receding. Preference for IBM machines (in particular, the IBM System /38) is on the rise. However, preference for VAX systems is also on the upswing, possibly leading to future improvements in Digital's commercial market share.
* While use of UNIX on VAX will increase, VMS will remain the dominant operating system for VAX systems. Also, many VAX users desire a heterogeneous (joint VMS and UNIX) operating environment.

2.1 SYSTEM USAGE

Using a five-point scale (1 = use it now, 2 = used to use it, 3 = have not used but familiar with family, 4 = aware of but not familiar with family, and 5 = never heard of it), respondents were asked to indicate their level of familiarity with 27 major families of minicomputers and mainframes. Figure 2.1 shows "current usage" results for the complete sample of respondents. Digital's VAX products are seen to have a very strong presence among respondents in the sample. VAX 11/7XX and MicroVAX are among the five most heavily used systems (IBM products occupy the other three positions) while the VAX 8XXX is rapidly acquiring market presence. In addition, VAXclusters are quite popular among VAX customers.

USAGE OF MAJOR SYSTEMS

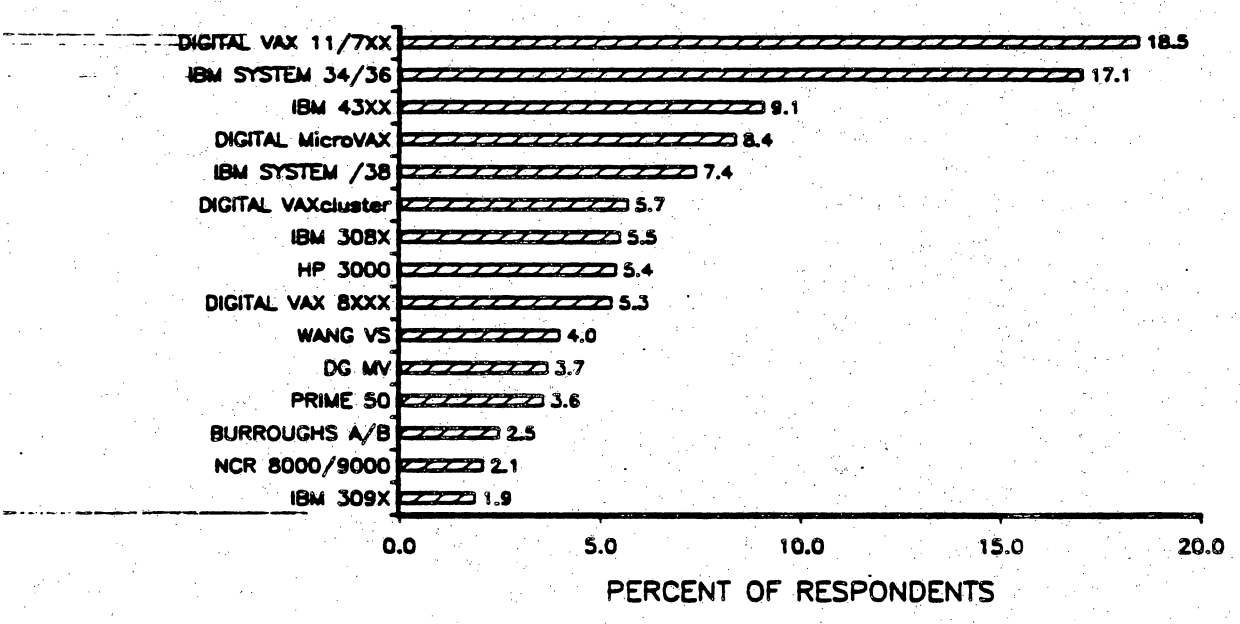


FIGURE 2.1

Due to the deliberate oversampling of technical customers in the VAX Positioning Study (to better reflect the Digital customer base), the overall usage results are not necessarily representative of the general market. However, comparing the usage results with those of last year's VAX Positioning Study (in which a similar sampling scheme was employed), it appears that Digital is at least retaining and most probably gaining market share with its new generation of VAX systems. However, as seen in the next section, these new VAX systems are predominantly being sold to the existing VAX customer base (i.e., users of VAX 11/7XX) and not to new customers.

Usage results for the two major application segments, "Business/Commercial" and "Scientific/Engineering", provide a more accurate assessment of the competitive position of major computer families. Figures 2.2 and 2.3 show "current usage" results for the "Business/Commercial" and "Scientific/Engineering" application segments, respectively. In commercial markets, IBM is clearly the vendor of choice. Figure 2.2 shows that near one-quarter of the respondents performing "Business/Commercial" applications are currently using the System 34/36 while 10% use the System /38, 9% use the 43XX, and 5% use the 308X. VAX 11/7XX and MicroVAX are being used by just over 10% and just under 5% of "Business/Commercial" respondents, respectively.

In technical markets, Digital appears to be widening its lead. As shown in Figure 2.3, Digital's new generation of VAX machines (the MicroVAX and VAX 8XXX) have quickly overtaken IBM machines in market presence. Nearly 16% of respondents performing "Scientific/Engineering" applications currently use MicroVAX while just under 11% currently use VAX 8XXX. In addition, VAXclusters appear to have extended the life of the VAX 11/7XX (as the VAX 11/7XX is still being used by one-third of all technical respondents). The leading IBM systems among "Scientific/Engineering" respondents are the System 34/36 with approximately 8% usage, 43XX with 7% usage (down somewhat from last year), 308X with 6% usage, and System /38 with 4% usage.

Clearly visible from the usage results is the fact that IBM remains Digital's only strategic threat in the general computer market. Among respondents performing "Business/Commercial" applications, over 40% use IBM products (either one or more of the following families: System 34/36, System /38, 43XX, 308X, or 309X) while just over 12% use Digital VAX products (one or more of the following: 11/7XX, MicroVAX, 8XXX, or VAXclusters). Among respondents performing "Engineering/Scientific applications, nearly 40% use Digital VAX products while about 20% use IBM products. In summary, IBM controls the commercial side of the market while Digital is in command of the technical side. No third vendor is a major strategic threat to either company at the present time.

USAGE FOR BUSINESS/COMMERCIAL APPLICATIONS

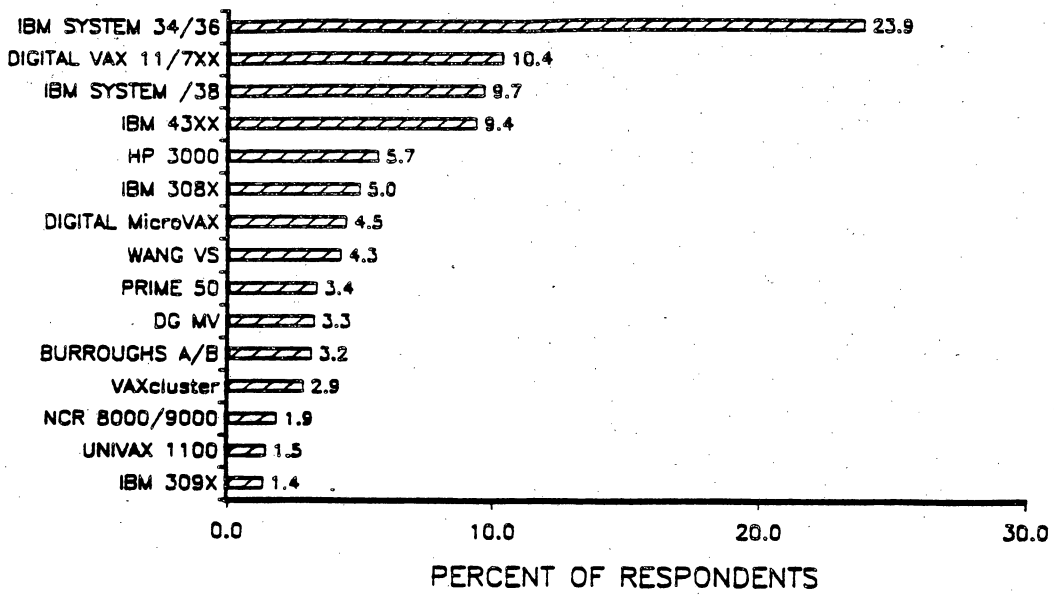


FIGURE 2.2

USAGE FOR SCIENTIFIC/ENGINEERING APPLICATIONS

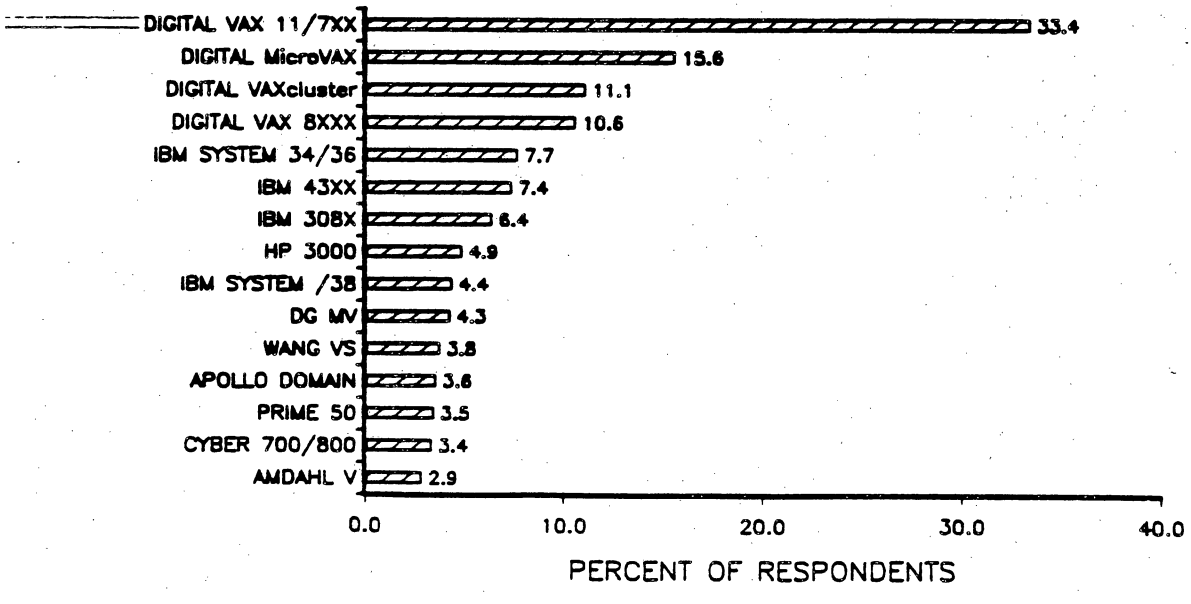


FIGURE 2.3

2.2 JOINT USAGE AND MIGRATION

The table below presents joint usage results among pairs of Digital and IBM products. For example, the table shows that 90% of VAX 8XXX users are also users of VAX 11/7XX, indicating that the new VAX processors are predominantly being sold to the VAX customer base. [Not shown in the table are the results for MicroVAX. They too are largely being sold to the VAX customer base. Approximately 80% of MicroVAX users are also users of VAX 11/7XX.] Also note that 63% of VAX 8XXX users are also users of VAXclusters. Combined with the above result, this indicates that most VAX 8XXX processors are being tied to existing VAX 11/7XX machines via VAXclusters.

Most striking among the joint usage results are the contrasts between Digital and IBM. Digital's VAX products play together and are therefore used together. In contrast, IBM products are used jointly with Digital products as often as they are used with other IBM products. Also eye-catching is the fact that the IBM System /38, being marketed as IBM's chief office system, is rarely used with other IBM machines. In summary, Digital's strengths in connectivity and compatibility are readily apparent from the table. In contrast, IBM systems are much more likely to be stand-alone machines.

	ALSO USE					
CURRENTLY USE	VAX 11/7XX	VAX 8XXX	VAX-clusters	IBM Sys /38	IBM 43XX	IBM 308X
VAX 11/7XX	-	27%	29%	5%	13%	10%
VAX 8XXX	90%	-	63%	5%	19%	15%
VAXclusters	90%	57%	-	5%	15%	13%
IBM Sys /38	12%	4%	4%	-	10%	6%
IBM 43XX	26%	11%	10%	8%	-	23%
IBM 308X	32%	15%	13%	8%	36%	-

The table below presents migration data from Digital VAX to certain IBM products and vice-versa. The table shows, for example, that 11% of former VAX family users currently use the IBM 43XX and 5% use the System /38. In contrast, 22% of former IBM 43XX customers currently use the VAX 11/7XX and 11% use the VAX 8XXX. Thus it appears that there is more migration from IBM to Digital products than from Digital to IBM products.

CURRENTLY USE

FORMERLY USED	NUMBER OF FORMER USERS	VAX 11/7XX	VAX 8XXX	IBM Sys /38	IBM 43XX
VAX family	304	-	-	5%	11%
IBM Sys /38	142	18%	7%	-	10%
IBM 43XX	347	22%	11%	11%	-

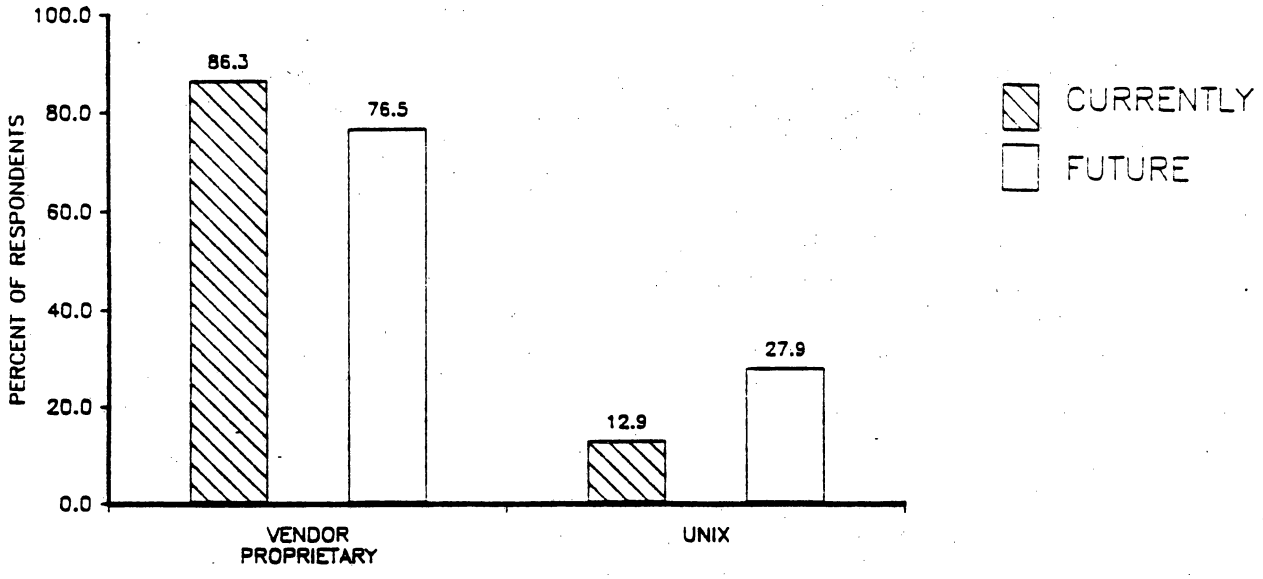
2.3 OPERATING SYSTEM USAGE

Figure 2.4 compares respondents' use of UNIX and the computer vendor's proprietary operating system on their primary computer systems in the 1986 and 1985 VAX Positioning Studies. Also shown is expected future use of UNIX and vendor proprietary operating systems. In this year's study, 13% of respondents currently use UNIX or a UNIX-derivative operating system while 28% expect to be using UNIX five years from now. The corresponding results for a vendor proprietary operating system are 86% for current use and 77% for future use.

In last year's study, the UNIX results were 11% current use and 28% future use; the vendor proprietary results were 83% current use and 65% future use. Therefore, the only dramatic change between this year's and last year's data is that use of the computer vendor's proprietary operating system is no longer expected to drop off very dramatically. And consequently, the need for heterogeneous (both UNIX and vendor proprietary) operating environments may gain popularity.

Among respondents in this year's study specifying VAX (any model) to be their primary computer system, 22% currently use UNIX while 38% expect to be using UNIX five years from now. Additionally, 88% indicate current use of the computer vendor's proprietary operating system (i.e., VMS) while 79% expect to be using a vendor proprietary operating system in the future. Thus while UNIX use on VAX systems will increase, VMS will remain the most popular VAX operating system. In many instances, VMS and UNIX will coexist in the VAX environment.

UNIX VS. VENDOR PROPRIETARY OPERATING SYSTEM USAGE – 1986



UNIX VS. VENDOR PROPRIETARY OPERATING SYSTEM USAGE – 1985

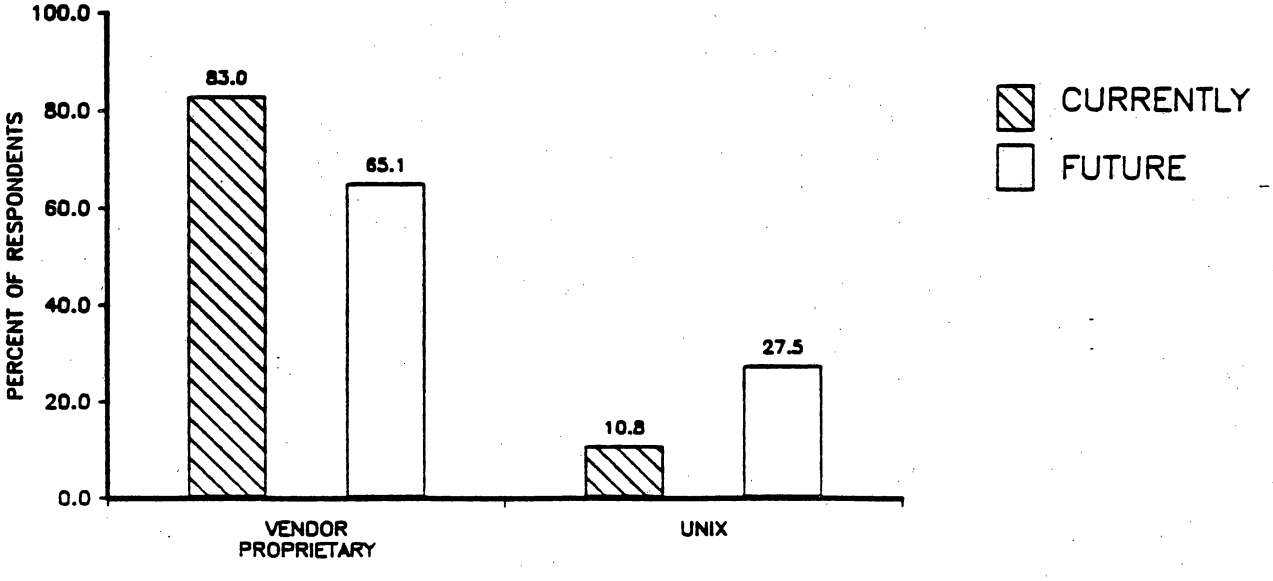


FIGURE 2.4

2.4 SYSTEM PREFERENCE

From a list of 27 major systems, respondents were asked to indicate their first and second choices of computers for Business/Commercial applications and for Engineering/Scientific applications. For each of the remaining systems (in each application area), respondents indicated whether they held a favorable, neutral, or unfavorable opinion of the system. Using a five-point scale (ranging from 1 for first choice to 5 for unfavorable opinion), average preference ratings can be computed for each system. Figures 2.5 and 2.6 show the highest rated systems in average preference for Business/Commercial applications and for Scientific/Engineering applications, respectively. In each figure, only those respondents performing the indicated applications (according to the classification of Section 1.2) are included in the computations. Not unexpectedly, VAX systems (VAX 8XXX, VAX 11/7XX, MicroVAX, and VAXclusters) receive the highest preference ratings for Scientific/Engineering applications while IBM systems (System /38, System 34/36, and 43XX) receive the highest ratings for Business/Commercial preference. However, the four VAX systems do rank among the top ten in average preference for Business/Commercial applications.

More revealing than average preference ratings are the "first choice" selections. Figures 2.7 and 2.8 show the highest ranked systems in terms of "first choice" selection for Business/Commercial applications and for Scientific/Engineering applications, respectively. Figure 2.7 clearly reveals IBM's dominant position in commercial markets. Over 60% of respondents performing Business/Commercial applications select an IBM machine as their first choice, a result slightly greater than that found in last year's study. The System /38 is the preferred system for nearly 23% of respondents while the System 34/36 is the preferred system for 18% of respondents. Other IBM machines (43XX, 308X, and 309X) are also preferred by a greater number of Business/Commercial respondents than any one of the Digital systems. Nevertheless, a combined 16% of Business/Commercial respondents prefer one of the four VAX systems (VAX 8XXX, VAX 11/7XX, VAXclusters, or MicroVAX), a solid increase over last year's result. Thus it would appear that both IBM and Digital are in position to increase their share of the Business/Commercial market (at the expense of other vendors).

Among respondents performing Scientific/Engineering applications, Digital's VAX systems are preferred by almost 50% of the respondents, a very significant increase over last year. Approximately 17% of respondents select VAX 8XXX as their first choice while the VAX 11/7XX is the preferred system for about 15% of respondents. These results are in stark contrast to the Scientific/Engineering preference results for IBM machines. Combined, IBM systems are preferred by just over 10% of respondents (with no single system being preferred by as many as 3% of respondents). Also, preference for the IBM 43XX is down considerably from last year. Interesting to note in the Scientific/ Engineering preference results is the relatively high incidence of "Other Systems" (i.e., those not included in the list of 27 systems) as the "first choice" selection. These other systems include such systems as the Digital PDP-11, HP 9000, and Sun workstations.

In summary, preference results confirm Digital's growing strengths in technical markets. The new generation of VAX products have quickly become favorites of technical customers. Coupled with low preference for IBM's current product set, Digital is in great position to increase its leadership position in technical markets. Conversely, IBM products (especially the System /38) are much preferred to Digital products in commercial markets. However, Digital's VAX products do appear to be making significant gains in preference among commercial customers.

MEAN PREFERENCE FOR
BUSINESS/COMMERCIAL APPLICATIONS

RANK	SYSTEM	MEAN RATING
1	IBM System /38	2.70
2	IBM System 34/36	3.05
3	IBM 43XX	3.24
4	HP 3000	3.31
5	Digital VAX 11/7XX	3.43
6	Digital VAX 8XXX	3.47
7	IBM 308X	3.50
8	IBM 309X	3.57
9	Digital MicroVAX	3.60
10	Digital VAXclusters	3.63

FIGURE 2.5

MEAN PREFERENCE FOR
SCIENTIFIC/ENGINEERING APPLICATIONS

RANK	SYSTEM	MEAN RATING
1	Digital VAX 8XXX	2.74
2	Digital VAX 11/7XX	2.75
3	Digital MicroVAX	3.12
4	Digital VAXclusters	3.12
5	CDC Cyber 700/800	3.40
6	HP 3000	3.40
7	Apollo DOMAIN	3.42
8	Amdahl V Series	3.72
9	Prime 50 Series	3.77
10	IBM 309X	3.79

FIGURE 2.6

FIRST CHOICE FOR BUSINESS/COMMERCIAL APPLICATIONS

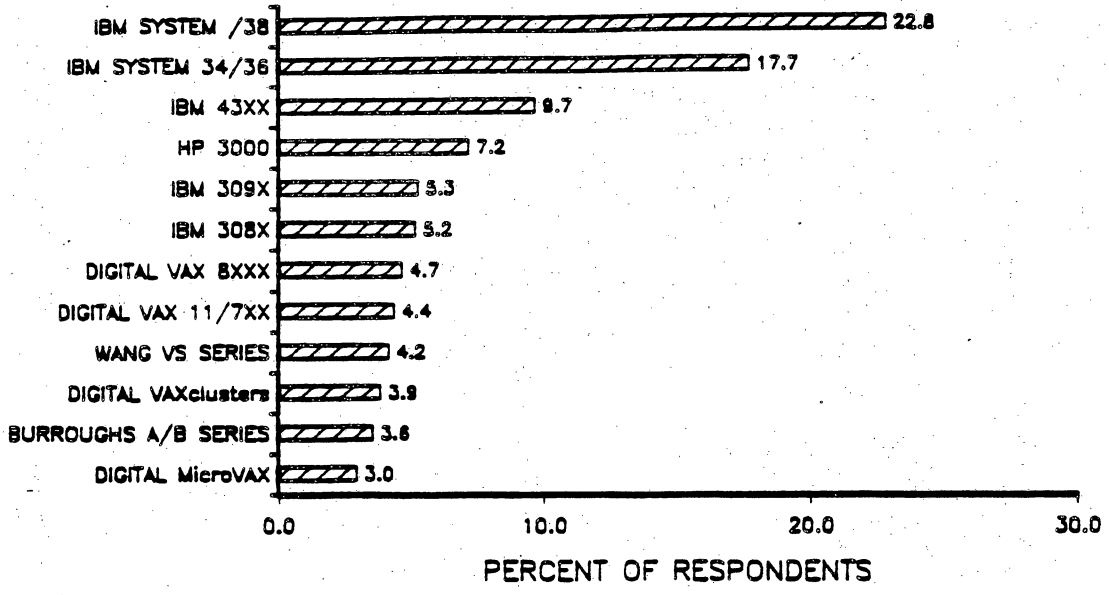


FIGURE 2.7

FIRST CHOICE FOR SCIENTIFIC/ENGINEERING APPLICATIONS

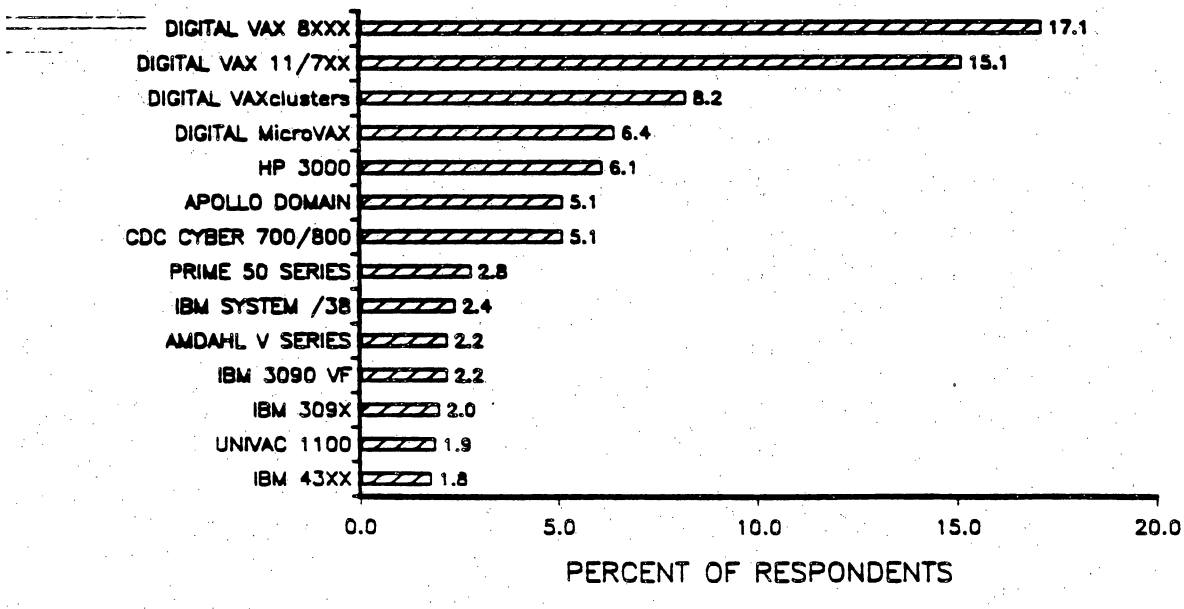


FIGURE 2.8

3.0 PERCEPTIONS OF MAJOR SYSTEMS

This chapter presents customer ratings of major computer systems along a complete set of product and vendor attributes. Both global comparisons for all systems competing in the U.S. market and head-to-head comparisons between Digital and IBM are made. Particular attention is given throughout the chapter to monitoring customer perceptions and competitive positioning of Digital systems announced within the past year. Changes in perceptions are noted that have taken place since the last study conducted one year ago.

The competitive positions of the 29 systems included in the study are also shown on perceptual maps, which are derived from the attribute ratings by a technique called factor analysis. The maps display aggregate perceptions of systems in a reduced set of dimensions, and therefore enable efficient system comparisons on a higher level. See Figure 3.9 for details on the exact grouping of attributes into seven perceptual dimensions.

VAXcluster, IBM 309X, IBM 3090-VF, and a few other systems have less than 20 respondents in their subsamples. They are included in the analysis for completeness. Caution should be used in forming conclusions about such minimally represented systems. The precision of their average ratings, however, is large enough to form many early impressions.

3.1 MAJOR FINDINGS

The major points to be brought forth in this section are:

* New Digital computer systems have shown improvement over the VAX 11/7XX systems in almost every dimension. The VAX 8XXX is perceived as superior to the older VAX's on hardware performance and price/value, and consistent in its excellent software environment and technical applications. Digital's interaction with VAX 8XXX customers has improved over the 11/7XX. Hardware and system reliability, however, are not seen as having improved for the VAX 8XXX over the VAX 11/7XX.

* Common users of high performance VAXes and large IBM mainframes see many advantages in VAX software, usability, and cost.

* MicroVAX is establishing a leading position in the technical market as a low-cost, compatible, reliable system, with strong systems software, business software, and office software.

* IBM System /38 is highly favored as a departmental business system. It has diverse strengths but also perceived weaknesses in compatibility, price, and technical features such as graphics and networking. This minicomputer is not likely to be displaced from its current position of strength in the commercial market.

* IBM's mainframe products are now seen as lagging in many important areas, including software environment, ease of use, price, networking, and family compatibility. These weaknesses open market opportunities for VAX. However, VAX is still seen as lagging these IBM systems in transaction processing, mass storage, and marketing support, which are key determinants of success in commercial markets.

3.2 VAX POSITIONING

The major VAX Study findings on customer perceptions are organized below into the seven dimensions by which customers evaluate competing computer systems. These dimensions are:

* Hardware Performance
* System Software
* Customer Interaction
* System Reliability
* Business Capabilities
* Product Price
* Technical Capabilities

Readers may find supporting data in the reduced rank table of Digital and IBM systems found on Figure 3.5. and in the complete rank table on Figure 3.10 with all 29 systems.

3.3 HARDWARE PERFORMANCE

The hardware dimension consists of these attributes: Compute Power: Mass Storage: Memory Management: Transaction Processing Responsiveness: Real-Time Capability: Meets All My Needs: and File and Data Base Management. Some key findings are:

* VAX 8XXX is ranked #6 in Mass Storage. #11 in Compute Power. and #11 in Real-Time Capability out of 29 systems in the study. These represent advances in perception over the VAX 11/7XX. which remains in the bottom half in these areas.
* VAXclusters systems do not appear to meet customer expectations on a number of performance measures. VAXclusters were ranked #23 in Compute Power. #25 in Real-Time Capability. and #27 in Transaction Processing Responsiveness. The Compute Power ranking is particularly far from what we might expect. and may be indicative of customer frustration of not being able to tune performance.
* MicroVAX is ranked #7 in Compute Power. #14 in Real-Time Capability. and #19 in Mass Storage. Each is an improvement over the VAX 11/7XX. except Mass Storage. The high ranking in computer power may be indicative of more dedicated MIPS than before - which end users fully appreciate.
* Digital is seen to offer the same excellent Memory Management across the entire VAX line. each with a top 10 ranking.
* IBM mainframe systems have clear strengths. The 308X is ranked #7 in Mass Storage and #8 in Compute Power. Last year. however. the 308X was rated #3 in Compute Power. The newer 3090 shows improvement despite a small sample: it is rated #2 in each of these attributes.
* The Cray offers great power. Its strength is made evident by its #1 rank in both Compute Power and Mass Storage.

In summary, although the newer IBM mainframes have strengths, their leading position in hardware performance has somewhat eroded by the arrival of the new VAX family of products. The VAX 8XXX is seen to offer performance competitive with IBM mainframes (although overall dissatisfaction with these mainframes may have contributed to lower ratings on their performance). The older 43XX and VAX 11/7XX lines are perceived as average, both having dropped from leading status. (See the perceptual maps in Figures 3.1 and 3.4)

3.4 SYSTEMS SOFTWARE

The system software dimension consists of: Operating Systems: Software Utilities and Tools: Ease of Use: Family Compatibility: High Level Languages: Documentation: and Architecture. Key findings are:

* MicroVAX, VAX 8XXX, and especially VAXcluster have made gains beyond the already strong VAX 11/7XX. In Ease of Use the MicroVAX is ranked #2, VAX 8XXX #7, and VAXcluster #3, while the VAX 11/7XX is ranked #11.
* Customers perceive VAXcluster to have superlative software: it is rated among the top 3 systems on ALL systems software attribute scales.
* Poor usability and incompatibility have hurt the IBM mainframe systems. Both older and newer mainframes are ranked #22 or worse in Ease of Use. IBM systems, even System /38, have trouble with Family Compatibility. Only the 309X is rated among the top 10 systems in Compatibility.
* Customers see the established 43XX and 308X as having mediocre software: both are ranked in the bottom half on ALL systems software attributes.
* Burroughs is among the leaders in systems software. It is top-ranked in Ease of Use, and ranked #2 in Operating Systems.

System Software is an area of formidable strength for Digital, and severe deficiency for IBM's mainframe products. Since the last study, Digital has widened its lead over IBM in systems software. IBM software has become openly problematic and is seen as generally inferior, showing a severe drop from its above average position last year. (See the perceptual map in Figure 3.1)

3.5 CUSTOMER INTERACTION

This dimension consists of: Salespeople: Ease of Doing Business With Vendor: Vendor Integrity: Software Support People: Vendor Reputation: and Hardware Service. Key findings are:

* Although the sample is small, VAXclusters have moved into a very competitive position in this traditional weak spot for Digital. VAXclusters are ranked #8 in Ease of Doing Business with Vendor and #1 in Knowledge of Salespeople. They are ranked #7 in Vendor Integrity and #2 in Vendor Reputation.

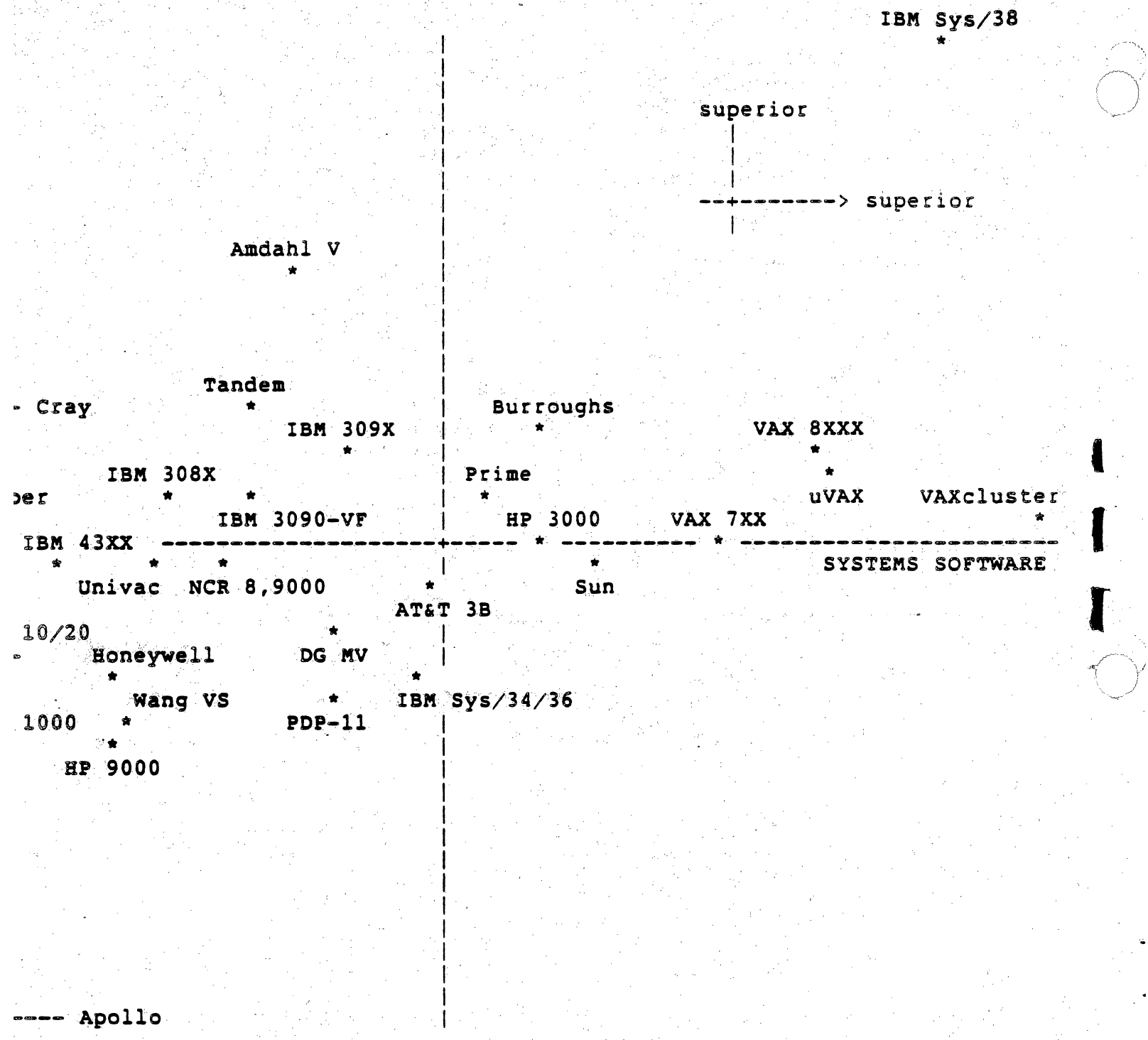

IBM Sys/38
superior
superior
Amdahl V
Tandem
Cray
IBM 309X
Burroughs
VAX 8XXX
IBM 308X
Prime
uVAX
VAXcluster
IBM 3090-VF
HP 3000
VAX 7XX
IBM 43XX
SYSTEMS SOFTWARE
Univac
NCR 8,9000
Sun
AT&T 3B
10/20
Honeywell
DG MV
Wang VS
IBM Sys/34/36
1000
PDP-11
HP 9000
Apollo

FIGURE 3.1

* Digital is having some difficulty interacting with customers who purchase VAX 11 7XX and VAX 8XXX systems, but there are signs of improvement. Each system ranks between #14 and #20 in Knowledge of Salespeople and Ease of Doing Business. However, the VAX 8XXX is ranked #2 in Skill of Software Support and clearly leads all VAX systems in this area.

* MicroVAX is struggling with customer interaction. It is ranked in the bottom one-third in Knowledge of Salespeople, Ease of Doing Business, and Skill of Software Support. However, as with the VAX 8XXX, Digital integrity and reputation are solid with a rank of #8 in these areas.

* IBM is having greater success selling customers its mid-range 43XX product line, than it is the 308X. Customers rate the 43XX among the top 10 systems in ALL customer interaction attributes.

* The 308X is ranked #7 in Salespeople, #9 in Software Support, and #10 in Hardware Service, but it struggles elsewhere. Customers rate the 308X #19 in Ease of Doing Business, and #16 in Vendor Integrity. IBM has backtracked after the gain seen last year in its ability to sell the 308X to customers.

* Hewlett-Packard systems appear consistently in the top 10 among the 29 systems in customer interaction attributes.

Digital has made some positive strides into this traditional bastion of IBM strength. But Digital still has a long way to grow. Purchasers of high-performance VAX systems have indicated improved perception of Digital salespeople, business practices, support, and service. But Digital is still far from achieving parity with IBM in its ability to interact with customers. (See the perceptual map on Figure 3.2)

3.6 SYSTEM RELIABILITY

System Reliability consists of these attributes: System Never Fails: Hardware Reliability: Bug-Free Software: Requires Minimal On-site Expertise: Overall Quality. Important findings include:

* While VAX systems are still seen as lagging in reliability, VAXclusters and MicroVAX are becoming more competitive with IBM. MicroVAX is ranked #10 in Hardware Reliability, and VAXcluster is ranked #5. Clusters have improved customer perceptions of VAX reliability.

* Both VAX 11/7XX and VAX 8XXX are in the lower half among the 29 systems in both System Never Fails and Hardware Reliability.

* VAX systems ALL received top 10 rankings in Bug-Free Software.

* IBM 308X has remained generally deficient in this area since 1984. It is ranked #13 in Hardware Reliability, #14 in System Never Fails, and #17 in Bug-Free Software.

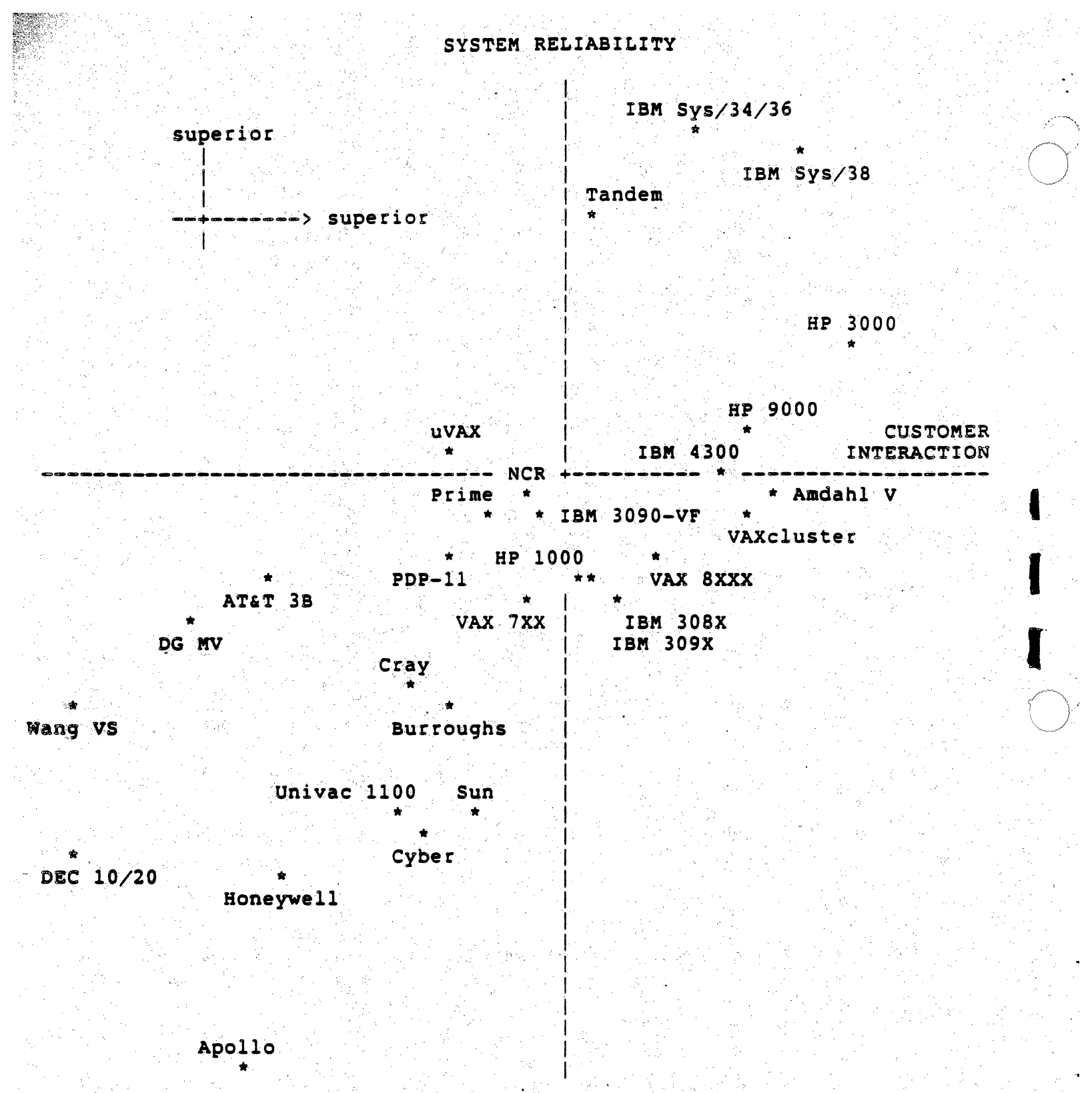

SYSTEM RELIABILITY
superior
superior
IBM Sys/34/36
IBM Sys/38
Tandem
HP 3000
HP 9000
uVAX
IBM 4300
CUSTOMER
INTERACTION
NCR
Prime
Amdahl V
IBM 3090-VF
VAXcluster
HP 1000
PDP-11
VAX 8XXX
AT&T 3B
VAX 7XX
IBM 308X
DG MV
IBM 309X
Cray
Wang VS
Burroughs
Univac 1100
Sun
Cyber
DEC 10/20
Honeywell
Apollo

FIGURE 3.2

* IBM 43XX is ranked #4 in Hardware Reliability, but is ranked #13 in Bug-Free Software. Customers no longer believe that the 4300 series offers the above average system reliability.

* Tandem has established a niche. It is ranked #1 in System Never Fails and #1 in Bug-Free Software.

This area has been an Achilles heel for Digital. VAX systems have been perceived as lagging IBM in reliability by a reasonably wide margin. This year, however, there are some bright spots for Digital, along with some decreasing perceptions of IBM. VAXclusters and MicroVAX are making headway. However, the high performance and mid-range VAX systems must still exhibit increased reliability by orders of magnitude to be seen as equivalent to large IBM systems (see the perceptual map in Figure 3.2).

3.7 BUSINESS CAPABILITY

The business capability dimension is defined by these attributes: Suitability as an Office Information System: Word Processing Software: Hardware Packaging: and Terminals/ Workstations/PC's. The findings are:

* MicroVAX is perceived to be a leader, with ratings in the top 10 among the 29 systems in ALL business attributes.

* VAX 8XXX is ranked #7 in Business/Commercial Software, which is an improvement over the VAX 11/7XX (rank #13).

* The new VAX systems, led by MicroVAX (rank #6), are seen to be more Suitable Office Information Systems than the VAX 11/7XX (rank #14). IBM mainframes lag in this area, while System /38 is a leader with rank #4.

* Word Processing Software is a competitive edge belonging to Digital. VAX systems are ALL rated in the top 10 on this attribute. The IBM systems are seen to be uniformly poor, even the System /38.

* IBM is very strong in Business/Commercial Software. The mainframes are each ranked by customers in the top 5 among the 29 systems.

* Wang VS, Sun, and AT&T 3B are each strong in this area.

This dimension, which focuses on office capabilities, is an area in which Digital and IBM are very competitive. Each vendor offers unique strengths. IBM is strong on the desk, while Digital office environment is clearly perceived to be superior (See the perceptual map on Figure 3.3)

3.8 TECHNICAL CAPABILITY

The technical dimension is defined by: Graphics: Engineering/Scientific Software: Hardcopy/Printing/Plotting Devices: and Networking. Major findings are:

* VAX systems are ALL strong in Engineering/Scientific Software, Graphics, and Networking Products. Each system is ranked in the top 10 for these three important attributes.

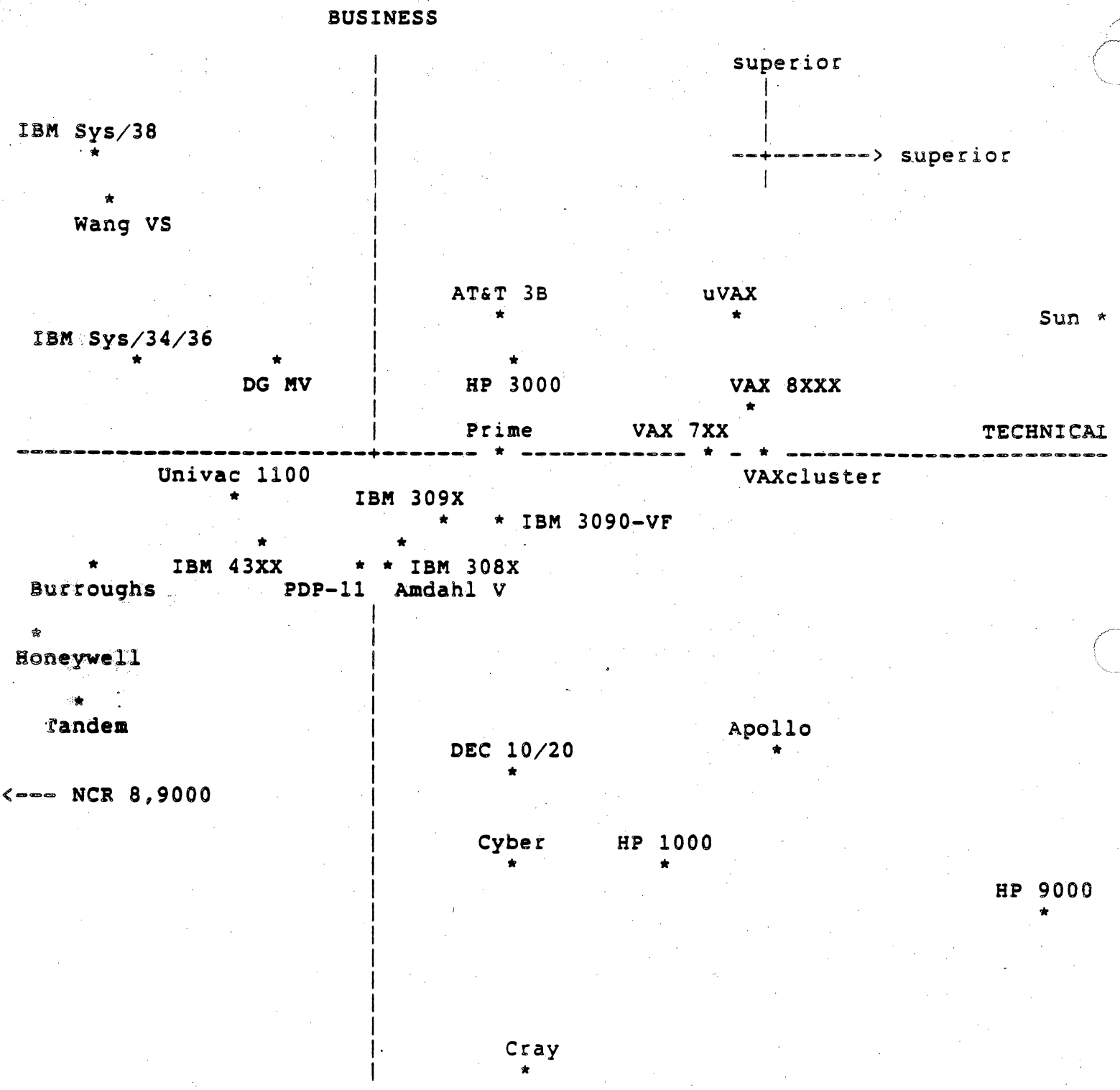

BUSINESS
superior
superior
IBM Sys/38
Wang VS
AT&T 3B
uVAX
Sun
IBM Sys/34/36
DG MV
HP 3000
VAX 8XXX
Prime
VAX 7XX
TECHNICAL
Univac 1100
VAXcluster
IBM 309X
IBM 3090-VF
IBM 43XX
IBM 308X
Burroughs
PDP-11
Amdahl V
Honeywell
Tandem
Apollo
DEC 10/20
<--- NCR 8,9000
Cyber
HP 1000
HP 9000
Cray

FIGURE 3.3

* IBM systems, small and large, are uniformly weak in technical capability. Each system is ranked in the lower half among 29 systems in the three technical attributes.
* Hewlett-Packard is seen as a technical leader. The HP 9000 is ranked #1 in Engineering/Scientific Software and #3 in Graphics. HP systems are ALL perceived among the top 10 systems in Graphics.
* Sun is an established leader in workstations. Its customers rate it #1 in Graphics, #1 in Networking, and #4 in Engineering/Scientific Software.
* Apollo Domain is still strong technically. It is rated #2 in Graphics, #5 in Networking, and #10 in Engineering/Scientific Software.

Beyond the PC's, IBM has no serious threat in the technical market. Some competition comes from Sun, HP9000, and Apollo. Thus, it appears that Digital is the unchallenged leader in technical markets in the mid-range and high performance systems space, but is facing strong competition on the desk (See the perceptual map on Figure 3.3)

3.9 PRICE

The last factor to be consider is price, which customers define as: Priced Below Similar Systems; Software Price; and Life Cycle Cost. Key findings are:

* The 8XXX, VAXcluster, and MicroVAX are rated #7, #8, #9 in System Price, whereas the VAX 11/7XX is rated #17, similar to 1985.
* VAX 8XXX is the only Digital system that is perceived to offer software at a competitive price. The 8XXX, in the top 10 among the 29 systems in ALL price attributes, is rated #5 in Software Price, but the other VAXes are rated in the lower one-third.
* MicroVAX is already seen to be a leader in cost over its lifetime. It is rated #3 in Life Cycle Cost. The VAX 11/7XX is rated #17.
* The IBM systems are ALL rated in the bottom one-third with rankings of #21 or worse in System Price. They are seen to be uniformly expensive.
* System /38 is the only IBM system perceived to offer low-cost software. It is rated #6 in Software Price, the 43XX rated #25, and the 308X rated #26 in this area.
* Others systems offered at competitive cost are AT&T 3B, NCR 8000/9000, Sun, Burroughs, and DG MV.

Digital has greatly improved its price-performance position with the VAX 8XXX and the MicroVAX. The new VAX cost advantages should prove to be a potent leverage in sales as the company enters the 1990's. IBM systems are seen widely as offering poor price-performance, except the System /38 (See the perceptual map on Figure 3.4)

HARDWARE PERFORMANCE

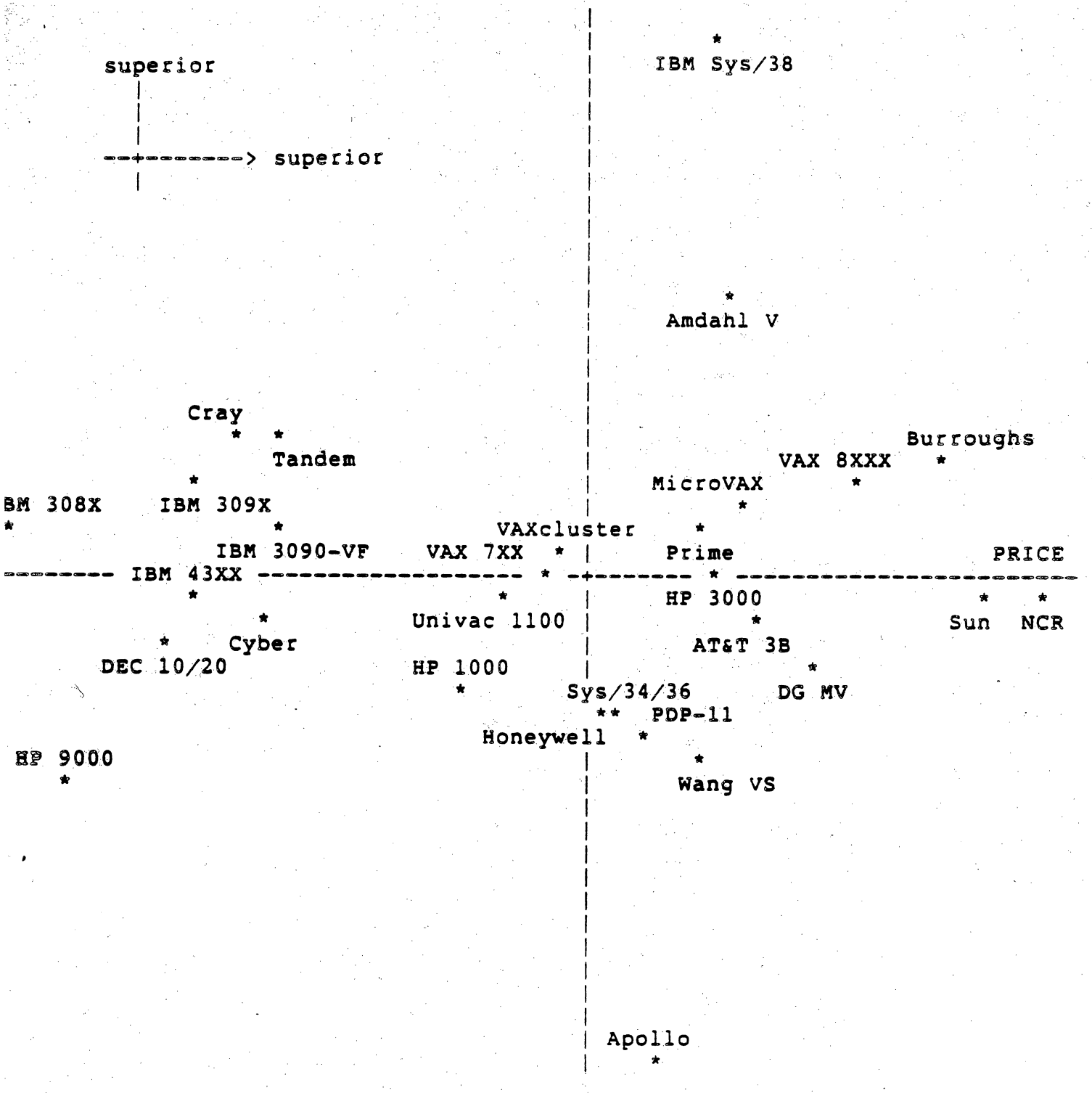


FIGURE 3.4

MAJOR SYSTEMS PERFORMANCE ON KEY ATTRIBUTES
among 29 systems overall

ATTRIBUTE	VAX cluster	VAX 8XXX	IBM 309X	IBM 308X	IBM 43XX	VAX 11/7XX	uVAX	SYS 38
		*		*				
Compute Power	-	10	2	8	-	-	7	5
Mass Storage	-	6	2	7	8	-	-	5
Real-Time Capability	-	-	-	-	-	-	-	2
TP Responsiveness	-	-	2	-	10	-	-	3
Operating System	3	9	8	-	-	7	5	1
Ease of Use	3	7	-	-	-	-	8	2
High Level Languages	1	3	7	-	-	4	5	2
Family Compatibility	3	6	9	-	-	5	2	-
Skill of Salespeople	1	-	5	7	6	-	-	9
Ease of Doing Business	8	-	-	-	10	-	-	5
Vendor Integrity	7	9	6	-	4	-	8	2
HW Reliability	5	-	8	-	4	-	10	2
System Never Fails	-	-	-	-	8	-	-	3
Bug-Free Software	8	10	-	-	-	9	7	2
Business Commercial SW	-	7	1	3	5	-	9	4
Engineering/Sci Software	5	7	-	-	-	6	8	-
Networking	2	3	8	-	-	6	4	-
Life Cycle Cost	-	5	-	-	-	-	3	4
Overall Quality	1	5	8	10	-	9	3	2

FIGURE 3.5

Notes: An asterisk(*) means less than 20 cases in the study. A minus(-) means the system is not in the top 10 among 29 systems.

3.10 IBM VERSUS DIGITAL SYSTEMS

LOW END:

Among low-end systems, both IBM System /38 and Digital MicroVAX were rated high on many attributes by its customers. Both these systems have standalone departmental applications and can also serve as entry points to the computing environments of the two largest computer vendors, IBM and Digital. However, they compete in different markets. In fact, of the 219 respondents using System /38 and the 126 using MicroVAX, only 3 people currently use both. In the low-end, no controlled comparison can be made between the two systems: there are almost no common users.

Although the System /38 may be two to four times as costly as the MicroVAX, it is worthwhile to compare the strengths of the two systems. They are the low-end computer systems in their respective company's product lines.

By simple inspection of their ranks, however, some areas can be identified as strengths. IBM System /38 is stronger than the MicroVAX primarily in reliability and customer interaction areas. The MicroVAX is comparatively stronger in attributes that have been traditional Digital strengths. In order of magnitude, some distinguishing strengths are:

MicroVAX STRENGTHS	IBM System /38 STRENGTHS
Engineering & Scientific SW	Ease of Doing Business
Networking Products	Skill of Software Support
Graphics Capabilities	Transaction Responsiveness
Family Compatibility	Mass Storage
Priced Below Similar Systems	Hardware Service
Word Processing	Software Price
	Knowledge of Salespeople
	Real-Time Capability
	System Never Fails
	File and Database Management
	Hardware Reliability

FIGURE 3.6

Note: Attributes are called strengths due to large differences in rank.

MID RANGE:

The mid-range is an old battleground. VAX 11/7XX and IBM 43XX have competed for the last five years. Even though each system is represented in every primary application, the 43XX is used mostly in MIS and manufacturing, and the 11/7XX is used mostly in scientific research, design engineering, and software development. Each claims to be a multi-purpose system. Of the 522 respondents using VAX 11/7XX and the 263 using IBM 43XX, 40 people currently use both systems. Thus a detailed comparison is possible of the advantages of both systems using only people who are familiar with both systems. The technique employed for this comparison is the statistical T-test, in a controlled setting.

The T-test technique can be used to identify, in a statistically valid way, the system which exhibits clear superiority in an attribute. The table below presents attributes which are 11/7XX advantages, and those which are 43XX advantages. Each attribute listed is a significant advantage in the view of customers, under a controlled hypothesis test at the 10% level. Attributes for which the T-test reveals no conclusive superiority between the two systems are not presented. The 40 common users point out the following advantages, in order of magnitude:

VAX 11/7XX ADVANTAGES	IBM 43XX ADVANTAGES
Engineering & Scientific SW	Knowledge of Salespeople
Ease of Use	Hardware Service
Requires Minimum Expertise	Operating System
Family Compatibility	
Software Price	
Architecture	

FIGURE 3.7

Note: Attributes are called advantages due to significance at 10% level.

HIGH END:

The high end is the newest arena where Digital has marshaled its forces and put its reputation on the line. The company wants to make significant inroads in the large commercial market by competing successfully against IBM. The company claims "to have it now" and customers are echoing the message to us!

In half a year, the large VAXes have courted and won a piece of the commercial market, openly proclaiming its superiority in connectivity. Customers of these large VAXes, some of which serve as a component system to a VAXcluster, are generally happy. But they come largely from the present VAX customer base. Nevertheless, inroads to commercial customers do exist as a result of limited success experienced by VAX 11/7XX. Of the 171 respondents using large IBM mainframes, and the 78 using high-performance VAXes, 19 people currently use both. Although the common sample is small, a useful comparison is possible that reveals the advantages of each system. The technique utilized is again the statistical T-test, in a controlled setting, since the 19 people are familiar with both systems. Advantages are revealed from hypothesis test at the 10% level.

The table below lists attributes which are high performance VAX advantages, and those which are IBM large mainframe advantages. The high performance VAX group consists of the VAX 8XXX and VAXcluster. Attributes for which the T-test reveals no conclusive superiority are not presented. The 19 common users point out a host of familiar VAX advantages, but with cost as leverage. In order of their magnitude, early significant advantages are:

High-End VAX Advantages	IBM 308X, 309X Advantages
Engineering & Scientific SW	System Never Fails
Ease of Use	
Life Cycle Cost	
Software Price	
System Price	
Word Processing System	

FIGURE 3.8

Note: Attributes are called advantages due to significance at 10% level.

3.A APPENDIX: SYSTEM FACTORS AND RANK TABLE

Factor analysis can be a useful tool to group the complete set of vendor and product attributes into a reduced set of perceptual dimensions. A perceptual dimension, or evaluative criterion, consists of a group of attributes which share strong positive correlations. Correlations between perceptual dimensions are typically negligible. Grouping the entire set of 37 attributes into a few perceptual dimensions realistically addresses the evaluation process whereby customers tend to rely on a small number of key evaluative criteria in rating systems. The higher level dimensions simplify the process whereby Digital management can internalize large scale results.

Factor analysis reveals seven perceptual dimensions in the 1986 VAX Positioning Study. Each dimension is shown in Figure 3.9 with the attributes that are closely associated with it. The grouping into seven factors is substantially consistent with the results of the 1984 and 1985 VAX Positioning Studies.

Slight adjustments are evident in customer perceptions in two dimensions:

* The Systems Software dimension has grown to include both Ease of Use and Family Compatibility. This change works into Digital strength but into IBM weakness.
* Bug-Free Software now contributes to the Systems Reliability dimension, which enhances the general perception of Digital reliability.
* Overall Quality, a nebulous summary attribute, is most closely associated with the System Reliability dimension. In addition, it has rather high correlation with the Systems Software dimension.

The attribute groups, called factors or perceptual dimensions here, are very useful when observing the perceptions of major systems. Competitive positions of the many systems are displayed in an appropriate pair of dimensions in perceptual maps. The breakdown into groups of attributes depends entirely on the data, and is not directed by the researcher. Names of the seven attribute groups are chosen with liberty in an effort to describe them in an accurate way. The component attributes of each dimension are ordered according to their correlations with the aggregate factor score. The attribute appearing first within a factor contributes the most to that factor.

PERCEPTUAL DIMENSIONS OF COMPUTER SYSTEMS

ASSOCIATED ATTRIBUTES	FACTOR
Compute Power Mass Storage Memory Management Transaction Processing Responsiveness Real-Time Capability Meets All My Needs File & Database Management	HARDWARE PERFORMANCE
Operating Systems SW Utilities & Tools Ease of Use Family Compatibility High Level Languages Documentation Architecture	SYSTEMS SOFTWARE
Knowledge of Salespeople Ease of Doing Business Vendor Integrity Skill of Software Support People Vendor Reputation Hardware Service	CUSTOMER INTERACTION
System Never Fails Hardware Reliability Bug-Free Software Requires Minimal Expertise Overall Quality	SYSTEM RELIABILITY
Business/Commercial Software Suitable as Office Information System Word Processing Software Terminals/Work Stations/PCs Hardware Packaging	BUSINESS CAPABILITY
Priced Below Similar Systems Software Price Life Cycle Cost	PRODUCT PRICE
Graphics Engineering/Scientific Software Hardcopy/Printing/Plotting Devices Networking Products	TECHNICAL CAPABILITY

FIGURE 3.9

	Compute Power	Mass Storage	Memory Management	Transaction Responsiveness	Real-Time Capability	Meets All My Needs	File & Database Mgmt	Operating Systems	Tools & Utilities	Ease of Use	Family Compatibility	High Level Languages	Documentation	Architecture	Salespeople	Ease of Doing Business	Vendor Integrity	Skill of SW Support	Vendor Reputation	HW Service
DEC VAX 11/7XX	20	11	6	22	19	10	12	7	8	11	5	4	4	9	16	20	14	12	12	15
DEC VAX 8XXX	11	6	8	18	11	6	17	9	5	7	6	3	3	6	14	16	9	2	6	11
DEC VAXcluster	23	16	2	27	25	16	11	3	3	3	3	1	2	3	1	8	7	18	2	9
DEC MicroVAX	7	19	9	20	14	4	9	5	4	8	2	5	7	7	21	27	8	22	8	17
DEC 10/20	6	28	7	11	17	15	25	16	27	9	29	21	10	27	28	29	27	29	20	26
DEC PDP-11	28	23	26	25	4	25	19	15	16	15	18	12	9	19	20	23	15	16	13	16
IBM Sys/34,36	21	26	23	15	22	5	23	14	12	4	23	24	5	23	8	9	5	13	4	7
IBM System/38	5	5	1	3	2	1	1	1	2	2	22	2	1	1	9	5	2	4	3	3
IBM 43XX	13	8	17	10	23	13	20	23	22	27	16	18	15	20	6	10	4	6	5	6
IBM 308X	8	7	11	14	16	8	14	22	14	28	13	17	13	13	7	19	16	9	10	10
IBM 309X	2	2	5	2	29	28	5	8	6	22	9	7	19	12	5	14	6	10	7	18
IBM 3090-VF	17	10	4	21	27	3	6	13	9	26	17	23	8	17	24	21	3	15	15	2
3000	-	-	-	-	-	-	2	-	-	5	4	9	-	-	4	3	1	3	-	5
1000	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	6	10	-	-	-
HP 9000	-	-	-	-	8	-	-	-	10	-	-	-	-	-	2	7	-	8	-	1
AMDAHL V	4	4	3	4	9	7	10	-	-	-	-	-	6	2	3	1	-	1	-	8
APOLLO Domain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AT&T 3B	-	-	-	9	-	-	8	6	7	-	-	-	-	8	-	-	-	-	-	-
BURROUGHS	9	-	-	6	5	-	3	2	-	1	-	-	-	10	-	4	-	-	-	-
CRAY	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CYBER 700,800	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DG MV	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-	-	-	-	-
HONEYWELL DPS	-	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NCR 8000,9000	-	9	-	5	6	-	-	-	-	-	8	-	-	-	-	2	-	-	-	4
PRIME	10	-	10	8	10	-	7	10	-	10	1	-	-	-	-	-	-	-	-	-
SUN	-	-	-	-	-	2	-	4	1	-	-	6	-	4	-	-	-	7	9	-
TANDEM NS	-	-	-	1	3	-	4	-	-	-	10	10	-	5	10	-	-	5	1	-
UNIVAC 1100	-	-	-	-	7	-	-	-	-	-	-	8	-	-	-	-	-	-	-	-
WANG VS	-	-	-	-	-	9	-	-	-	6	-	-	-	-	-	-	-	-	-	-

FIGURE 3.10

	System Never Fails	Hardware Reliability	Bug-Free Software	Requires Min Expertise	Overall Quality	Business/Commercial Software	Suitable Office Info System	Word Processing Software	Terminals/PCs/Workstations	Hardware Packaging	System Price	Software Price	Life Cycle Cost	Graphics	Eng/sci Software	Hardcopy/Plot/Print	Networking
VAX 11/7XX	18	20	9	13	9	13	13	8	15	17	17	20	17	9	6	6	6
VAX 8XXX	23	17	10	8	5	7	11	6	17	3	7	5	5	8	7	8	3
VAXcluster	28	5	8	16	1	12	10	9	21	7	8	21	26	6	5	19	2
MicroVAX	12	10	7	9	3	9	6	5	9	1	9	19	3	5	8	12	4
10/20	27	27	18	26	15	26	18	25	12	29	26	27	29	14	9	20	14
PDP-11	13	18	11	11	20	10	16	14	18	19	14	14	9	19	14	14	19
Sys/34,36	2	1	4	1	7	2	8	12	2	16	22	18	12	24	26	15	25
System/38	3	2	2	7	2	4	4	11	1	4	21	6	4	22	29	17	20
43XX	8	4	13	22	18	5	19	21	8	22	24	25	20	21	22	16	15
308X	14	13	17	24	10	3	23	22	7	26	27	26	28	15	18	10	11
309X	21	8	15	29	8	1	24	16	22	23	29	23	15	12	17	18	8
3090-VF	22	3	5	25	17	18	20	7	14	27	23	15	23	13	12	5	12
000	6	6	6	4	4	8	9	-	4	6	-	-	7	7	-	3	-
000	10	7	-	-	-	-	-	-	10	-	-	-	8	4	-	2	-
000	5	-	-	-	-	-	-	-	5	-	-	-	-	3	1	1	-
IL V	4	-	3	-	-	6	-	-	-	-	1	-	-	-	-	9	-
O Domain	-	-	-	-	-	-	-	-	-	-	6	-	-	2	10	-	5
3B	7	-	-	10	-	-	3	3	-	10	-	1	1	10	-	-	7
UGHS	-	-	-	5	-	-	-	-	-	-	5	2	6	-	-	-	-
	-	-	-	-	-	-	-	-	-	5	-	-	-	-	2	-	-
700,800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-
	-	-	-	-	-	-	5	2	-	-	4	9	10	-	-	-	-
WELL DPS	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-
000,9000	9	9	-	-	-	-	-	-	-	-	3	3	2	-	-	-	-
	-	-	-	3	-	-	7	-	-	9	-	10	-	-	-	-	10
	-	-	-	6	-	-	2	4	3	2	2	4	-	1	4	4	1
M NS	1	-	1	-	6	-	-	-	-	8	-	-	-	-	-	-	9
AC 1100	-	-	-	-	-	-	-	10	-	-	10	8	-	-	-	-	-
VS	-	-	-	2	-	-	1	1	6	-	-	-	-	-	-	-	-

FIGURE 3.10 (CONT.)

4.0 IMPORTANCE OF ATTRIBUTES

This chapter presents information on the changing patterns of customer priorities. Customer priorities are measured both from direct elicited responses and through inference by statistical methods. Focus is given to the Commercial and Technical market segments. The importance of system attributes is investigated from different perspectives relating to two responses in the study:

* The importance of computer system attributes, as stated by the respondents to be most critical toward their purchase decision. Such responses are tracked in studies conducted in the last three years.
* The attributes that are the most significant predictors of preference. The preference score of an individual system is regressed against its ratings on 36 vendor and product attributes, a procedure which reveals the particular subset of attributes critical to its preference. Important attributes are identified in the two main market segments.

4.1 PATTERNS OF ATTRIBUTE IMPORTANCE (SELF-STATED)

Self-stated importance is developed by having the respondents indicate the eight most critical system and vendor attributes (out of 36 in all) to their purchase decision. It is a direct method that points out which attributes, if any, motivate the purchase of computer systems.

Figure 4.1 shows the overall results of attribute importance, as stated by customers, in studies conducted in 1984, 1985, and the present 1986. Some key points evident in the table are:

* Hardware Reliability, Ease of Use, Bug-Free Software, and Hardware Service have remained the top four attributes since last year.
* Many of attributes associated with base computing technologies have increased in importance. Compute Power has risen dramatically in importance. It was ranked #29 and #30 in the last two years. Now it is ranked #10.
* Operating Systems and Family Compatibility have both risen somewhat in importance, moving up within the top 10. Also increasing in importance are: transaction processing responsiveness; real-time interface; price of software; and memory management.
* Many of the vendor attributes have decreased in importance. Vendor Integrity is declining in importance. It is ranked #13, but was formerly in the top 10. Also declining are vendor software support; ease of doing business with vendor; and requires minimal on-site expertise.

In summary, it can be concluded that customers are focusing more on base technologies, and placing much less emphasis on their vendor's resources. Customers appear to be taking more responsibility for their computing resources.

TABLE OF SELF-STATED ATTRIBUTE IMPORTANCE

ATTRIBUTE	RANK '86	RANK '85	RANK '84
HARDWARE RELIABILITY	1	1	1
EASE OF USE	2	2	2
BUG-FREE SOFTWARE	3	3	3
HARDWARE SERVICE	4	4	5
OPERATING SYSTEMS	5	8	4
FAMILY COMPATIBILITY	6	10	10
SOFTWARE UTILITIES	7	6	6
MEETS ALL MY NEEDS	8	9	11
DOCUMENTATION	9	5	7
COMPUTE POWER	10	29	30
DATA BASE MANAGEMENT	11	13	13
MEMORY MANAGEMENT	12	16	14
VENDOR INTEGRITY	13	7	9
TERMINALS/WS/PC	14	15	16
SKILL OF SW SUPT PEOPLE	15	11	12
HIGH-LEVEL LANGUAGES	16	12	8
REQ'S MINIMAL EXPERTISE	17	14	15
PRICE OF SOFTWARE	18	21	22
SYSTEM NEVER FAILS	19	17	17
MASS STORAGE	20	20	18
LIFE CYCLE COST	21	18	19
TP RESPONSE	22	26	29
EASE OF DOING BUSINESS	23	19	21
WORD PROCESSING	24	23	26
ARCHITECTURE	25	24	20
REAL TIME INTERFACE	26	32	28
VENDOR REPUTATION	27	27	25
NETWORKING	28	24	24
BUSINESS/COMMERCIAL SW	29	22	23
PRICED COMPETITIVELY	30	34	31
SALES PEOPLE	31	33	35
SUITABLE AS OFFICE SYSTEM	32	30	33
PRINTING/PLOTTING DEVICES	33	31	32
GRAPHICS	34	31	32
ENGINEERING/SCIENTIFIC SW	35	28	27
PACKAGING	36	36	36

FIGURE 4.1

4.2 COMMERCIAL APPLICATIONS

A comparison is made between attributes that are stated to be important, against those attributes which are key indicators (predictors) of their preference for a system in a commercial environment. Attributes that predict system preference well are determined by their significance in regression methods. An attribute is said to have "derived importance" if its perception has strong correlation with system preference. Derived methods allow the identification of attributes which customers regard as critical in the formation of preference. Stepwise regression methods allow us to identify what is important, without direct involvement by the respondent.

Some key points bear mention upon comparing the inferred attribute importance (from derived methods) with the elicited importance (from self-stated):

* Vendor reputation and vendor integrity are critically important in the formation of system preference. These attributes are not foremost in customers' minds as they state their purchase priorities.
* High priority in commercial applications is stated for a reliable, easy to use, compatible system that offers good hardware service and bug-free software.
* For a system to be significantly more preferred in a commercial application, it should:

    * be reliable and easy to use
    * meet the computing needs
    * offer file management or DBMS
    * be compatible with existing systems

These findings are somewhat in contrast to the overall message that customers are focusing more on base technologies. This may be explained by the fact that many of the vendor attributes are still the most important determinants of preference in commercial applications (i.e., the derived importance measures), but that customer's increasingly state that they are concern with base technologies. The trend toward the increasing importance of base technologies is clearly measurable - but base technologies are by no means the dominant factor in the formation of commercial preference today. However, if the trend should continue, Digital will be in an increasingly strong position in commercial markets.

ATTRIBUTE IMPORTANCE
IN COMMERCIAL APPLICATIONS

SELF-STATED	DERIVED (FROM PREFERENCE)
1. Hardware Reliability	Hardware Reliability
2. Ease of Use	Vendor Reputation
3. Hardware Service	Meets All My Needs
4. Bug-Free Software	Ease of Use
5. Family Compatibility	Family Compatibility
6. Meets All My Needs	Vendor Integrity
7. File/Database Management	File/Database Management
8. Operating Systems	(-) High Level Languages
9. SW Utilities & Tools	System Never Fails
10. Documentation	(-) Mass Storage

FIGURE 4.2

Notes:
1. All derived attributes are statistically significant.
2. Attributes are listed in descending order of importance.
3. Attributes negatively influencing customer preference are denoted by a minus(-) in front of the attribute name.

An additional comparison of self-stated attribute importance is offered in the table in Figure 4.3 below. A simple system by system comparison reveals customer priorities for the major systems that compete in the business/commercial market. Some key points worth noting are that:

* System /38 customers differ from those who use the IBM mainframes in their stress of DBMS. ease of use. and software utilities.
* Hardware service is more critical to IBM customers. especially 43XX. than to VAX 11/7XX customers.
* IBM 308X customers stress operating systems and compute power more than other IBM customers.
* VAX 11/7XX and IBM System /38 customers both state a high importance for ease of use.

COMPARISON OF ATTRIBUTE IMPORTANCE BY SYSTEM IN COMMERCIAL APPLICATIONS

VAX 11 7XX SELF-STATED

1. Hardware Reliability
2. Ease of Use
3. Family Compatibility
4. Software Utilities & Tools
5. Bug-Free Software
6. Operating System
7. Meets All Needs
8. Documentation
9. File/Database Management
10. Hardware Service

IBM 43XX SELF-STATED

Hardware Reliability
Hardware Service
Family Compatibility
Operating Systems
Compute Power
Vendor Integrity
Bug-Free Software
Documentation
Skill Of Software Support
Meets All My Needs

IBM SYSTEM 38 SELF-STATED

1. Hardware Reliability
2. File/Database Management
3. Ease of Use
4. Family Compatibility
5. Hardware Service
6. High Level Languages
7. Memory Management
8. Software Utilities & Tools
9. Operating Systems
10. Compute Power

IBM 308X SELF-STATED

Hardware Reliability
Operating Systems
Compute Power
Family Compatibility
Hardware Service
Transaction Responsiveness
Networking Products
File/Database Management
Bug-Free Software
Memory Management

FIGURE 4.3

Notes:
1. All attributes listed are statistically important.
2. Attributes are listed in descending order of importance.

4.3 TECHNICAL APPLICATIONS

As in the commercial market in section 4.2. a comparison is made between attributes which are key indicators (predictors) of their preference for a system in a technical environment. An attribute has "derived importance" if its perception is highly correlated with system preference. as determined by regression methods. Indirect identification is possible of the attributes which customers regard as critical in their formation of preference. Results for the two main market segments are quite different.

Some key points are evident upon comparing the inferred importance with the elicited importance of attributes:

* Application software and meeting customer needs are critically important in the formation of system preference. These attributes are not stressed by customers as they state their purchase priorities.
* High priority in technical applications is for a reliable. powerful. easy to use system that comes with bug-free systems software. utilities languages. and scientific applications.
* For a system to be significantly more preferred in a technical application. it should:
    * come complete with very strong software
    * meet customer needs
    * have strong real time capabilities
    * be competitively priced

ATTRIBUTE IMPORTANCE
IN TECHNICAL APPLICATIONS

SELF-STATED	DERIVED (FROM PREFERENCE)
1. Hardware Reliability	Engineering/Scientific SW
2. SW Utilities & Tools	Meets All My Needs
3. Compute Power	Hardware Reliability
4. Operating Systems	Compute Power
5. Bug-Free Software	Real-Time Capability
6. Ease of Use	(-) Suitable Office Info System
7. High Level Languages	Vendor Integrity
8. Documentation	Life Cycle Cost
9. Family Compatibility	
10. Engineering/Scientific SW	

FIGURE 4.4

Notes:
1. All attributes listed are statistically important.
2. Attributes are listed in descending order of importance.
3. Attributes negatively influencing customer preference are denoted with (-) in front of the attribute name.

A deeper comparison of the important attributes is presented in the table in Figures 4.5 and 4.6 below. The two figures focus on the low-end systems and the high-end systems. No derived importance of attributes appears here. A direct system by system comparison reveals customer priorities for the major systems that compete in the engineering scientific market. Some key points worth mentioning are that:

* VAX customers in general stress software attributes such as utilities, languages, and operating systems.
* MicroVAX customers are the only ones to cite Architecture as important.
* VAX 8XXX customers surprisingly do not indicate Compute Power as very important in their purchase decision.
* The stated priorities of System /38 customers are extremely similar to those stated for commercial applications. It appears that the technical uses of System /38 are in support of commercial applications.
* IBM 43XX customers cite software attributes as very important, but this is an area of great weakness for this system.

COMPARISON OF ATTRIBUTE IMPORTANCE BY SYSTEM IN TECHNICAL APPLICATIONS

MicroVAX SELF-STATED

1. Hardware Reliability
2. Software Utilities & Tools
3. High Level Languages
4. Operating Systems
5. Architecture
6. Engineering/Scientific SW
7. Compute Power
8. Family Compatibility
9. Mass Storage
10. Graphics

SYSTEM /38 SELF-STATED

Hardware Reliability
File/Database Management
Ease of Use
Hardware Service
Meets All My Needs
Operating Systems
Software Utilities & Tools
High Level Languages
Memory Management
Compute Power

VAX 11/7XX SELF-STATED

1. Compute Power
2. Hardware Reliability
3. Software Utilities & Tools
4. Operating Systems
5. Engineering/Scientific SW
6. High Level Languages
7. Documentation
8. Bug-Free Software
9. Family Compatibility
10. Hardware Service

IBM 43XX SELF-STATED

Hardware Reliability
Bug-Free Software
Operating Systems
Software Utilities & Tools
Compute Power
Family Compatibility
HARDWARE SERVICE
High Level Languages
Graphics
File/Database Management

VAX 8XXX SELF-STATED

1. Software Utilities & Tools
2. Hardware Reliability
3. Operating Systems
4. Engineering/Scientific SW
5. High Level Languages
6. Networking Products
7. Compute Power
8. Hardware Service
9. Documentation
10. Graphics

IBM 308X SELF-STATED

Compute Power
Hardware Reliability
Operating Systems
Memory Management
Hardware Service
Bug-Free Software
Engineering/Scientific SW
Meets All My Needs
Documentation
Family Compatibility

FIGURE 4.5

Notes: 1. All attributes listed are statistically important.
2. Attributes are listed in descending order of importance.

5.0 CRITICAL STRATEGIC ISSUES

Three strategic issues are examined in the 1986 VAX Positioning Study. The first concerns desired configurations of computers at the departmental and central resource levels. More specifically, desired computer configurations are deduced from respondent ratings of prototype computer configurations. The second issue pertains to customer use of, problems with, and purchase priorities for mass storage. The final issue concerns customer attitudes surrounding the topic of overall system reliability - definition of, factors affecting, and "price versus reliability" tradeoffs.

The major findings in this chapter include:

* Digital presently has the products (MicroVAX, VAX 8XXX, VAXclusters, and networks) to satisfy both the departmental and central computing resource needs of its customer base.
* To make inroads into the largest MIS/EDP shops (currently dominated by IBM supermainframes), Digital must substantially increase both the compute power and mass storage capacities of its present systems.
* A greater proportion of Digital VAX users than IBM mini/mainframe users indicate that it takes too long to access data from their mass storage devices.
* VAX customers perceive mass storage as the major contributor affecting their system's reliability.

5.1 COMPUTING REQUIREMENTS AT THE DEPARTMENTAL AND CENTRAL RESOURCE LEVELS

Respondents were asked to rate prototype "departmental" and "central resource" computing configurations based upon ability to satisfy the computing needs of their respective organizations. In particular, each respondent was presented with eight computing configurations, four departmental configurations and four central resource configurations. Respondents rated each configuration on a scale of 1 to 10, from "would not consider" to "definitely interested". If not familiar with his/her organization's departmental or central computing needs, a respondent was requested to refrain from rating the configurations. A total of 32 different departmental and 32 different central resource configurations were incorporated in the eight versions of the questionnaire.

A configuration consisted of four components or variables - MIPS per System, Number of Systems, Aggregate Mass Storage and Total Price. Each of the first three components varied across four levels (in both the departmental and central resource configurations) according to a fractional factorial design. The fourth component, Total Price, was set as the sum of the prices of the first three components (modified by a discount that also varied across four levels in the configurations according to the fractional factorial design). Using such a design, component levels varied in an equitable fashion across the alternative configurations. The technique of conjoint analysis was then used to determine the preferred attribute levels for various user segments.

Figures 5.1 through 5.6 show the results of conjoint analysis for departmental and central resource computing requirements. The figures present utility curves for the first three components (MIPS per System, Number of Systems, and Aggregate Mass Storage) for the departmental and central resource configurations. The horizontal axis of each graph represents the component levels. The vertical axis represents units of "utility", with the utility scale consistent across components. That is, users will be equally satisfied with a unit increase in utility on the MIPS per System graph as they are with a unit increase in utility on the Number of Systems graph.

Figures 5.1 through 5.3 depict departmental utility curves for users of VAX (both 11/7XX and 8XXX), IBM 43XX, MicroVAX, and System /38. Key findings include:

* Most VAX (11/7XX and 8XXX) users prefer a single departmental system with a performance level of 2 to 4 MIPS and disk storage of 2 to 4 Gigabytes.
* MicroVAX users are generally satisfied with the performance level of their present machines. In addition, MicroVAX users require up to 8 systems with aggregate mass storage of 2 Gigabytes (e.g., 250 MB for each of 8 systems) to meet their departmental computing requirements.
* IBM 43XX and System /38 users desire one departmental system with mass storage ranging from 1 to 4 Gigabytes. However, 43XX users require higher performance levels than System /38 users (4 MIPS for 43XX users versus .5 to 2 MIPS for System /38 users).

Figures 5.4 through 5.6 depict central computing resource utility curves for users of VAX (11/7XX and 8XXX), IBM 43XX, and IBM 308X. Key findings include:

* VAX users require from 2 to 8 systems with performance levels as high as 12 MIPS/System and disk storage of no greater than 10 Gigabytes for their central computing resource.
* IBM 308X users are satisfied with one very powerful system. Many 308X users exhibit an almost insatiable demand for compute power (108 MIPS and beyond) and a desire for as much as 100 Gigabytes of mass storage.
* IBM 43XX users require either 1 or 2 systems ranging in performance from 4 to 36 MIPS. Aggregate mass storage requirements are similar to those of VAX users.

Based on the above results, Digital customers should be extremely satisfied with the new generation of VAX machines. At the department level, either several MicroVAX systems (tied together with a LAN or a Low-End VAXcluster) or a mid-range VAX 8XXX system satisfy customer needs. For the central computing resource, large VAXclusters appear well suited for meeting the requirements of Digital customers. The new VAX processors also satisfy the needs of IBM customers at the departmental level, although hardware is only one aspect of the system sale. At the central resource level, very large VAXclusters (with tremendous amounts of mass storage) would be required to meet the hardware needs of the largest IBM customers.

DEPARTMENTAL: MIPS PER SYSTEM

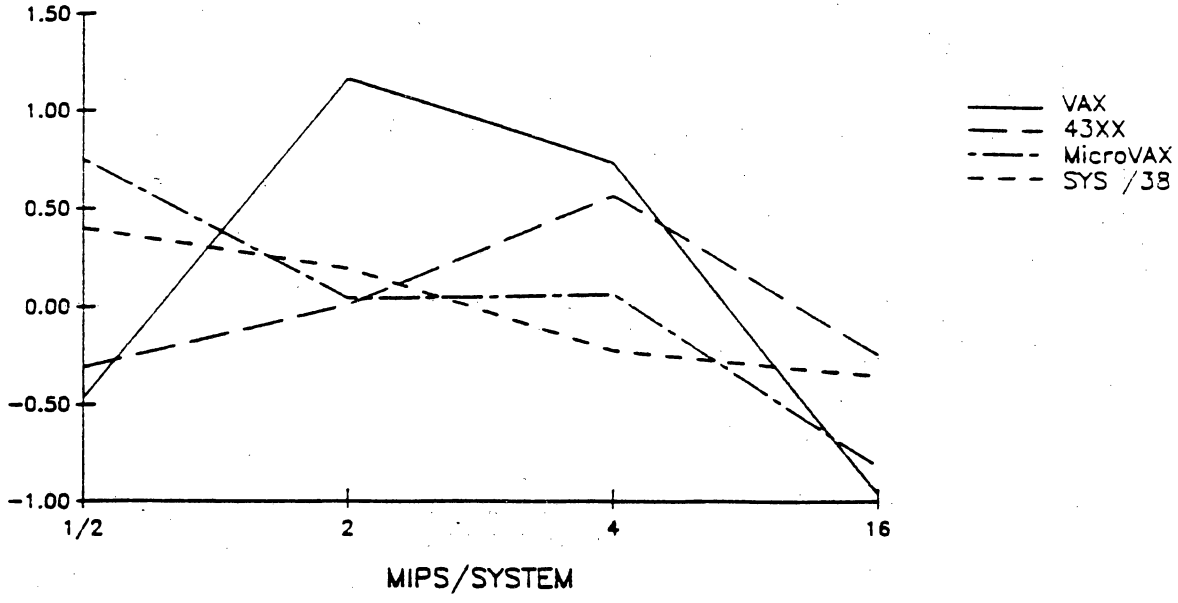


FIGURE 5.1

DEPARTMENTAL: NUMBER OF SYSTEMS

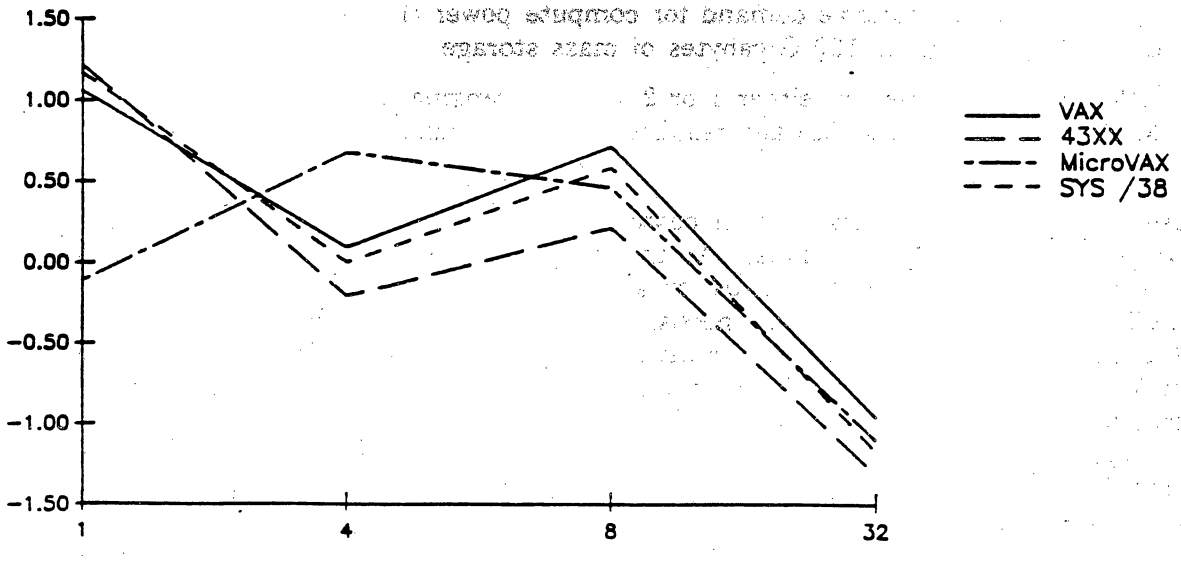


FIGURE 5.2

DEPARTMENTAL: AGGREGATE MASS STORAGE

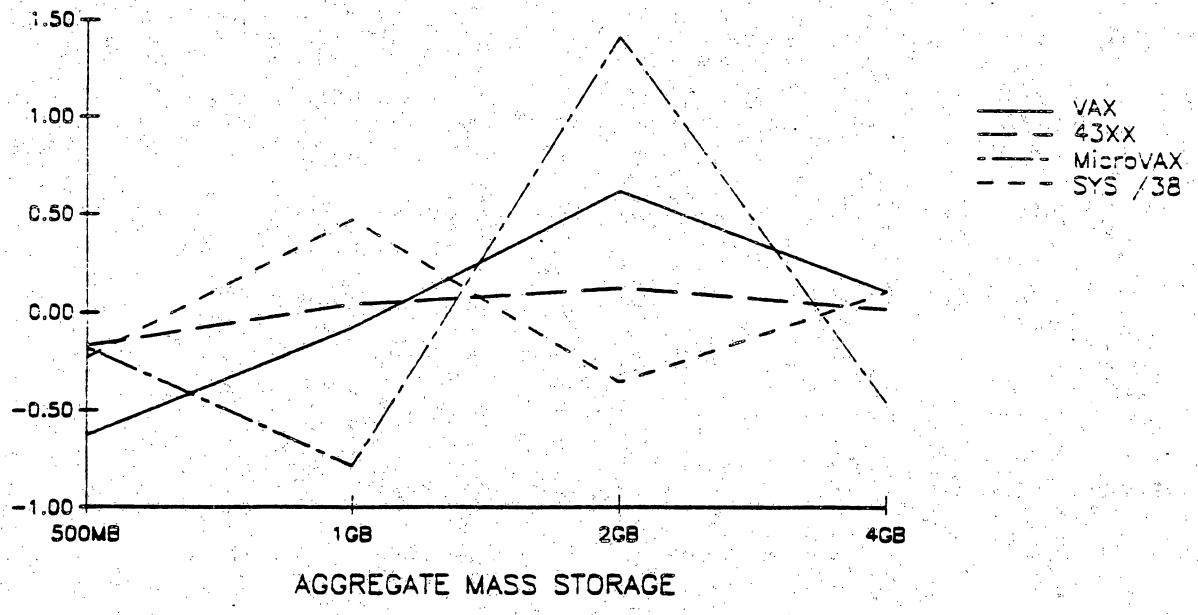


FIGURE 5.3

CENTRAL RESOURCE: MIPS PER SYSTEM

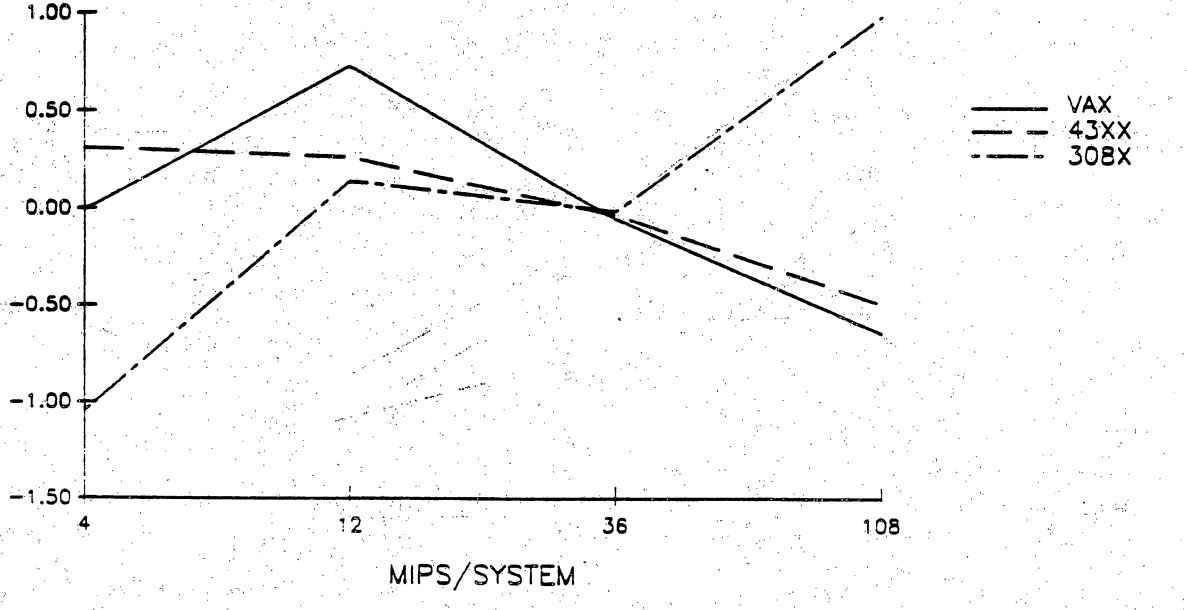


FIGURE 5.4

CENTRAL RESOURCE: NUMBER OF SYSTEMS

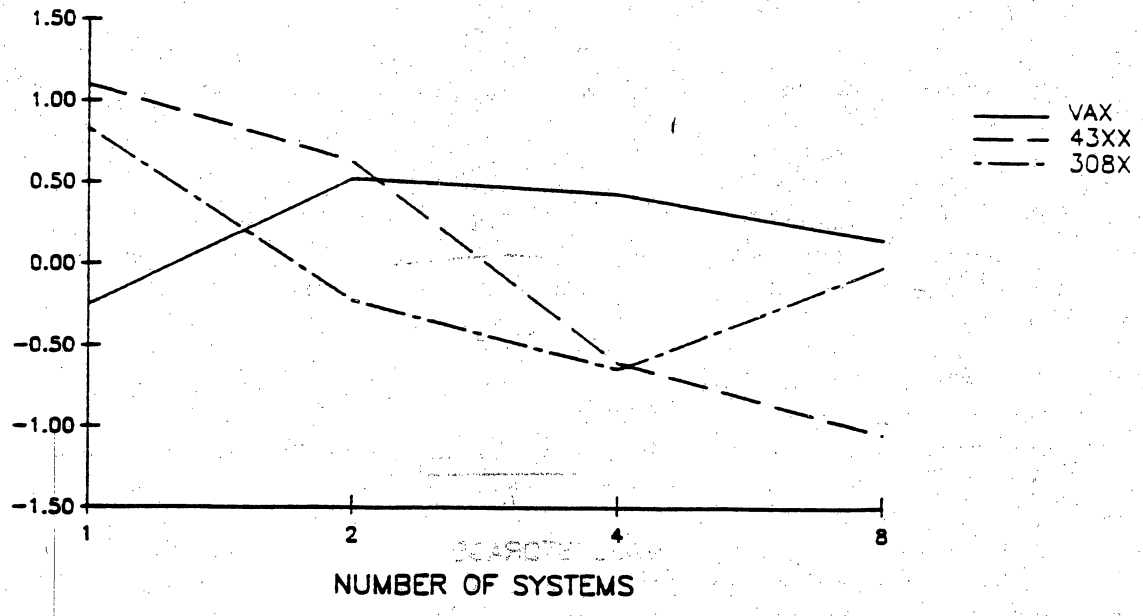


FIGURE 5.5

CENTRAL RESOURCE: AGGREGATE MASS STORAGE

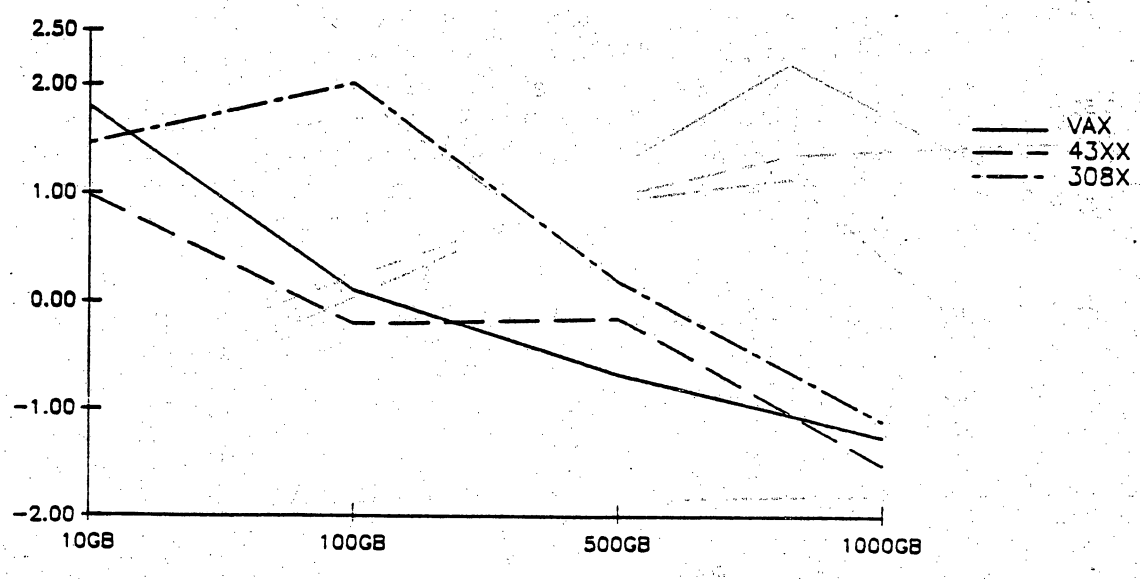


FIGURE 5.6

5.2 MASS STORAGE REQUIREMENTS

Respondents were asked a series of questions dealing with the level at which they typically access data, the problems they have accessing that data, and their purchase criterion for mass storage devices.

The level at which data was typically accessed was chosen from: local storage on single PC/work station, local storage on multiple PCs/work stations, shared storage on single group/departmental computer, shared storage on multiple group/departmental computers, central storage in an MIS/EDP computer room or transparent file storage on a distributed system.

A second question dealt with what, if any, were the major problems associated with accessing data. Possible answers included: takes too long to access, too difficult to access, too expensive and frequently not available. Finally, respondents were asked to prioritize their criterion for purchasing mass storage. Attributes such as access time, data transfer rate, capacity, reliability of sub-system, and cost per megabyte were listed with the instruction that respondents should denote their first, second and third priorities when making a mass storage purchase decision. Figures 5.7 through 5.9 summarize the results of this section. Among the more significant findings are:

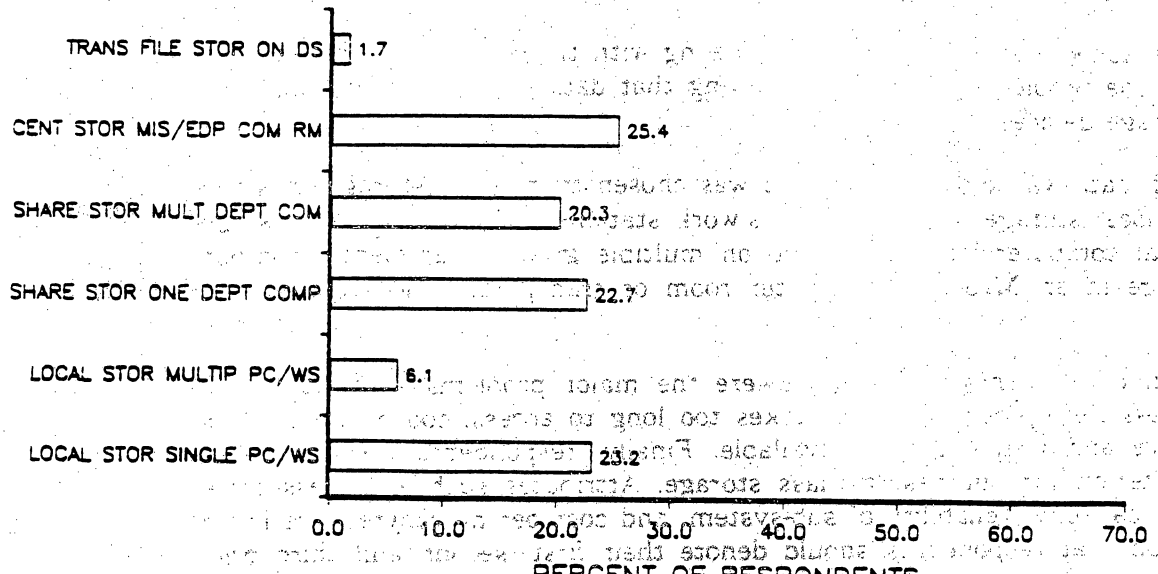
* IBM users access Central storage predominantly with Local PC storage a distant second. Digital users show much more balance between use of Central, Departmental and Local storage.
* Digital customers complain more frequently about data access taking too long than IBM customers. A very high proportion of MicroVAX customers in particular find data access too slow.

The mass storage level typically accessed is shown in figure 5.7. As would be expected, IBM's customers rely on a central MIS/EDP location for their storage needs. Digital's customers are much more likely to use local and departmental mass storage.

Figure 5.8 summarizes the customer's perception of the problem areas with mass storage. 35.2 percent of Digital customers (11/7XX, 8XXX, MicroVAX) think data access takes too long, as opposed to only 22.4 percent of IBM customers (308X, 309X, 43XX, Sys /38) feeling that way. At the same time, 59.2 percent of IBM customers see no problem with mass storage while only 47.5 percent of Digital customers think there is no problem. This trend is most apparent for MicroVAX customers, where 40.0 percent reported access takes too long and only 44.4 percent reported no problem.

As is shown in figure 5.9, there is general agreement that capacity, access time and sub-system reliability are the major criterion when purchasing mass storage.

MASS STORAGE LEVEL ACCESSED MOST FREQUENTLY (DIGITAL)



MASS STORAGE LEVEL ACCESSED MOST FREQUENTLY (IBM)

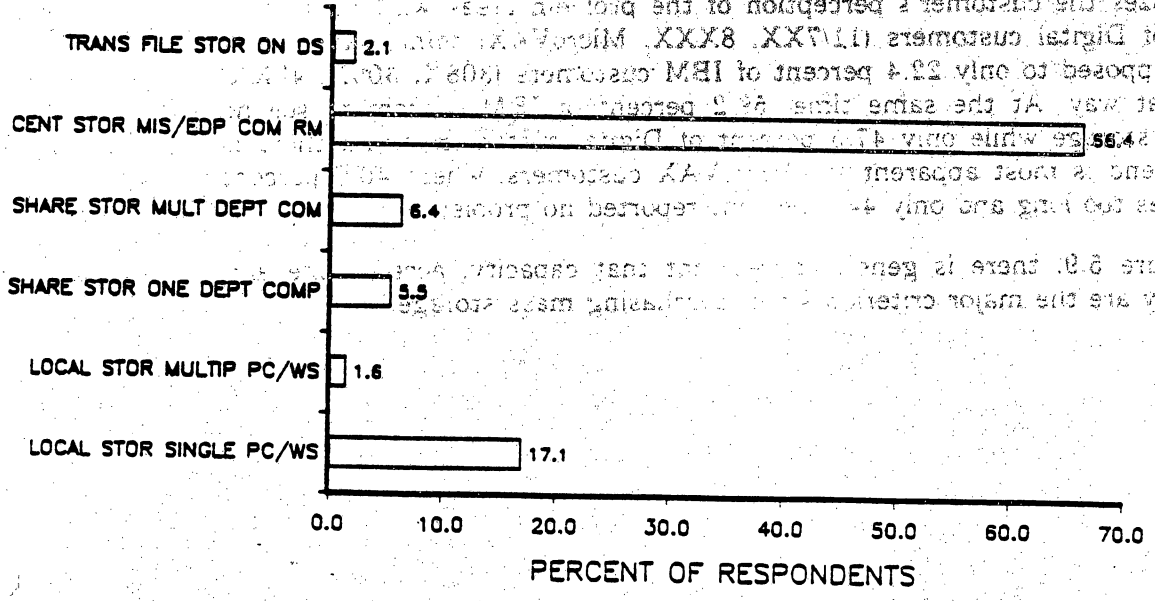


FIGURE 5.7

PROBLEMS WITH ACCESSING DATA

PRIMARY COMPUTER	308X 309X	43XX	S/38	VAX cluster	11/7XX 8XXX	MicroVAX
NO PROBLEM	48.1	60.1	65.4	60.0	47.4	44.4
TAKES TOO LONG	28.7	18.7	21.8	33.3	34.7	40.0
SOMETIMES NOT AVAILABLE	18.5	11.9	7.1	6.7	16.8	11.1

Above numbers represent percent of respondents indicating each problem type.

Note: VAXcluster sample size = 16

FIGURE 5.8

PURCHASE CRITERION FOR MASS STORAGE

PRIMARY COMPUTER	IBM	DIGITAL
RANK 1	ACCESS TIME	CAPACITY
2	CAPACITY	ACCESS TIME
3	RELIABILITY OF SUB-SYSTEM	RELIABILITY OF SUB-SYSTEM
4	DATA INTEGRITY	DATA TRANSFER RATE
5	DATA TRANSFER RATE	DATA INTEGRITY
6	COST PER MB	COST PER MB
7	COST OF SUB-SYSTEM	COST OF SUB-SYSTEM
8	SUB-SYSTEM BRAND NAME	COST OF MEDIA
9	COST OF MEDIA	SUB-SYSTEM BRAND NAME

FIGURE 5.9

5.3 RELIABILITY REQUIREMENTS

Three aspects of system reliability are addressed in this section:

- how the respondents measure reliability
- what factors most strongly affect their system's reliability
- how much more, percentage-wise, would the respondent be willing to pay for their current system if it were twice as reliable.

The respondents were given a list of possible reliability measurements (system uptime, application availability, frequency of service calls, etc.) and asked to choose at most two. They were next asked what most affects their system's reliability - local area network, wide area network, user errors, mass storage, CPU, application s/w, system s/w, vendor service, terminals/PCs/WSs, printer/plotters, or total system. Lastly, the respondents were asked how much more they would pay for their current system if it were twice as reliable. Possible answers ranged from 0% to 100% in 10% increments.

Figures 5.10 through 5.12 give a summary of the results. The key findings are:

* 11/7XX, 8XXX and MicroVAX customers perceive mass storage as the major contributor affecting their system's reliability.
* Customers are willing to pay a 16 to 18% premium for systems that are twice as reliable.

As is apparent in figure 5.10, system uptime is by far the most popular means of measuring reliability. Crash rate was a secondary measurement among MicroVAX and 11/7XX & 8XXX customers, but is not nearly as widely used as uptime.

Figure 5.11 dramatically illustrates that mass storage is seen as the major factor determining system reliability for 11/7XX, 8XXX and MicroVAX customers. Mass storage is identified as the primary system component affecting reliability for Digital products, but is rated third or fourth most important by IBM's customers. There is certainly a perception that Digital's storage systems have reliability problems. IBM customers see system and application software as having the most effect on reliability.

Finally, figure 5.12 shows, on the average how much more a customer would be willing to pay for their system if it were twice as reliable. There is surprising consistency between Digital and IBM customers and the various systems. All systems have averages between 16 and 18 percent except VAXclusters, where the mean percentage is 23. Since it is possible to configure a redundant cluster, these customers may have let their knowledge of cluster equipment pricing affect their answer.

CRITERIA USED TO MEASURE RELIABILITY

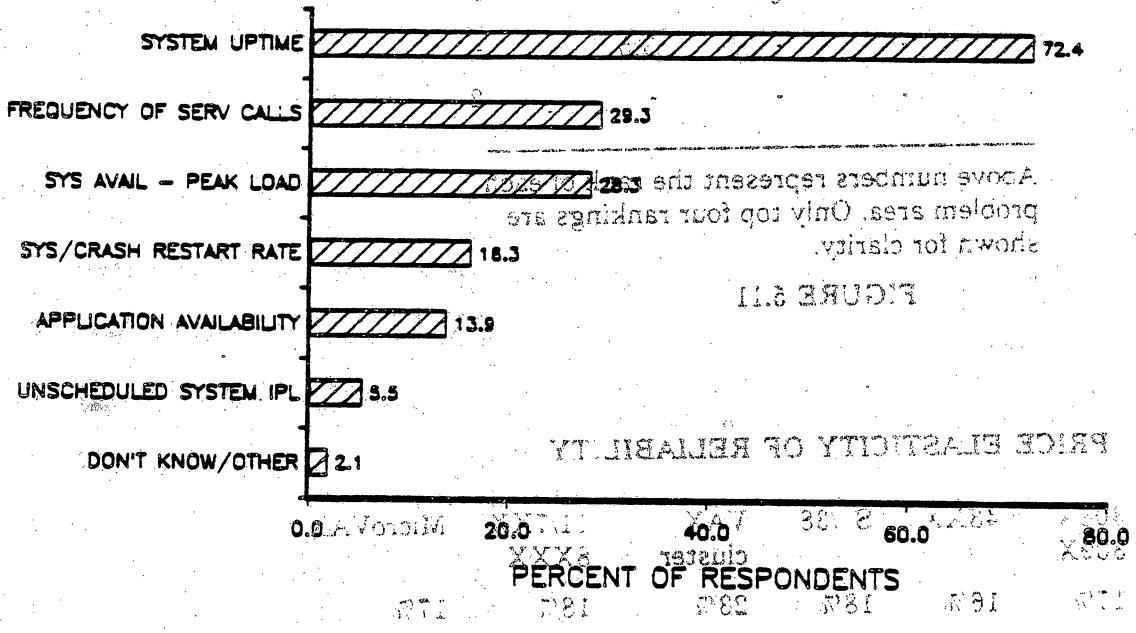


FIGURE 5.10

FACTORS AFFECTING SYSTEM'S RELIABILITY PERFORMANCE

PRIMARY COMPUTER	308X 309X	43XX	S /38	11/7XX 8XXX	MicroVAX
SYSTEM SOFTWARE	1	1	-	2	3
APPLICATION S/W	2	2	1	3.5	-
WIDE AREA NETWORK	3				
MASS STORAGE	4	3	4	1	1
USER ERRORS	-	4	2	-	4
CPU	-	-	3	-	-
TOTAL SYSTEM	-	-	-	3.5	-
DON'T KNOW	-	-	-	-	2

Above numbers represent the rank of each problem area. Only top four rankings are shown for clarity.

FIGURE 5.11

PRICE ELASTICITY OF RELIABILITY

PRIMARY COMPUTER	308X 309X	43XX	S /38	VAX cluster	11/7XX 8XXX	MicroVAX
MEAN PERCENT	17%	16%	18%	23%	18%	17%

FIGURE 5.12

ENGINEERING QUALITY TECHNOLOGY
STUDENT EVALUATION

Workshop name ______________________

Workshop dates ______________________

Instructor's name ______________________

(Student's name is optional)

Student's name ______________________

Student's job title ______________________

Student's VP ______________________

Length of time at Digital ______________________

1. List five things that you learned that you will apply back on your job.

   1.
   2.
   3.
   4.
   5.

2. What did you expect to learn but did not?

3. What did you like the most ?

4. What did you like the least ?

5. What would you do to improve the workshop ?

6. To whom would you recommend this workshop ?
(be specific & we will notify these people of future offerings)

7. Where did you hear about this workshop ?

___word of mouth
___over the terminal
___a Digital publication (specify)
___from my manager
___from the site training org
___other (specify)

______________________ ______________________

ENGINEERING QUALITY TECHNOLOGY
STUDENT EVALUATION

Workshop name_____
Workshop dates_____
Instructor's name_____

(Student's name is optional)
Student's name_____
Student's job title_____
Student's VP_____
Length of time at Digital_____

1. List five things that you learned that you will apply back on your job.

   1.
   2.
   3.
   4.
   5.

2. What did you expect to learn but did not?

3. What did you like the most ?

4. What did you like the least ?

5. What would you do to improve the workshop ?

6. To whom would you recommend this workshop ?
(be specific & we will notify these people of future offerings)

7. Where did you hear about this workshop ?

___word of mouth
___over the terminal
___a Digital publication (specify)
_____

___from my manager
___from the site training org.
___other (specify)
_____

Please rate each of the following aspects of the course.
very poor-1— — 2— — 3— — 4— — 5-very good

1.	Overall Rating of this Course	1	2	3	4	5	NA
2.	The clarity of the course objectives	1	2	3	4	5	NA
3.	The knowledge of the instructor(s) (instructor will list)						
	a.	1	2	3	4	5	NA
	b.	1	2	3	4	5	NA
	c.	1	2	3	4	5	NA
	d.	1	2	3	4	5	NA
	e.	1	2	3	4	5	NA
	f.	1	2	3	4	5	NA
	g.	1	2	3	4	5	NA
	h.	1	2	3	4	5	NA
4.	The instructor(s) as effective teacher(s) (instructor will list)						
	a.	1	2	3	4	5	NA
	b.	1	2	3	4	5	NA
	c.	1	2	3	4	5	NA
	d.	1	2	3	4	5	NA
	e.	1	2	3	4	5	NA
	f.	1	2	3	4	5	NA
	g.	1	2	3	4	5	NA
	h.	1	2	3	4	5	NA
5.	Interaction and Discussion	1	2	3	4	5	NA
6.	Lectures	1	2	3	4	5	NA
7.	Exercises	1	2	3	4	5	NA
8.	Notebook organization	1	2	3	4	5	NA
9.	Homework	1	2	3	4	5	NA
10.	Use of terminal	1	2	3	4	5	NA
11.	Use of videotapes (instructor will list)	1	2	3	4	5	NA
	a.	1	2	3	4	5	NA
	b.	1	2	3	4	5	NA
	c.	1	2	3	4	5	NA
	d.	1	2	3	4	5	NA
12.	Workshop Duration	too long,		too short,		just right	
13.	Workshop Pace	too fast,		too slow,		just right	
14.	Length of Sessions	too long,		too short,		just right	